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PHOTOVOLTAIC SYSTEMS DESIGN MANUAL

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MICROMEDIA

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PHOTOVOLTAIC SYSTEMS DESIGN MANUAL

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PREFACE

Photovoltaic systems are electric generators that produce direct current (DC) electricity from solar energy. They normally consist of arrays of photovoltaic or solar modules supplying power to battery storage or directly to a DC load or an AC load through an inverter.

Photovoltaic systems use no fuel and are also non-polluting, noiseless, and require very little maintenance. They are therefore ideal for supplying power in remote locations off the electrical grid. The most common applications for photovoltaic systems are remote communications facilities, monitoring equipment, and warning devices. They are also being increasingly used for remote pumping, refrigeration, and lighting in remote locations.

This manual will assist potential users of photovoltaic systems to understand how they work and how to design and install a system. The handbook is divided into three parts:

SECTION A: PHOTOVOLTAIC SYSTEMS AND APPLICATIONS (CHAPTERS 1 AND 2)

An introduction describing different types of photovoltaic systems and applications, and showing how the amount of solar energy available in a given location can be determined.

SECTION B: COMPONENTS OF PHOTOVOLTAIC SYSTEMS (CHAPTERS 3 TO 8)

An introduction to components commonly used in photovoltaic systems, including photovoltaic modules and arrays, batteries, power conditioners, and support structures.

SECTION C: SYSTEM DESIGN AND INSTALLATION (CHAPTERS 9 TO 16)

A guide to photovoltaic system design, covering load analysis, system sizing, component selection, and economics, as well as installation testing, and maintenance.

The manual is written in a popular style but assumes that the reader has some familiarity with the basic concepts of physics and electricity and has some technical expertise on how to design, specify and install power systems.

The manual will give assistance in understanding the concepts of photovoltaic systems and their design. It cannot, however, take the place of a qualified and experienced design technician. It is meant as an aid to communications engineers, users of remote monitoring and warning devices, and power system contractors who supply the remote market.

PREFACE

Les systèmes photovoltaïques sont des générateurs électriques qui produisent de l'électricité en courant continu (cc) à partir de l'énergie solaire. Ils se composent normalement de champs de modules photovoltaïques qui fournissent de l'énergie à des accumulateurs ou directement à une charge cc ou encore à une charge ca par l'intermédiaire d'un onduleur.

Ces systèmes ne consomment pas de combustible; ils ne polluent pas, ne font pas de bruit et exigent très peu d'entretien. Ce sont donc des moyens idéaux d'alimenter des installations situées dans des endroits reculés, à l'écart du réseau de distribution électrique. Les systèmes photovoltaïques servent surtout à alimenter des installations de communication, du matériel de surveillance et des dispositifs d'avertissement situés dans des endroits reculés. On s'en sert aussi de plus en plus pour le pompage, la réfrigération et l'éclairage là où l'on n'a pas accès au réseau électrique.

Les renseignements donnés ici visent à aider les éventuels utilisateurs de systèmes photovoltaïques à en comprendre le fonctionnement et à savoir comment les concevoir et les installer. Ils se répartissent en trois grandes rubriques :

SECTION A : LE SYSTEME PHOTOVOLTAIQUE ET SES UTILISATIONS (CHAPITRES 1 ET 2)

Introduction aux divers genres de systèmes photovoltaïques et à leurs usages, ainsi qu'à la façon de calculer l'énergie solaire disponible dans un endroit déterminé.

SECTION B : LES ELEMENTS DU SYSTEME PHOTOVOLTAIQUE (CHAPITRES 3 A 8)

Introduction aux éléments d'emploi courant dans le système photovoltaïque : modules et champs photovoltaïques, accumulateurs, conditionneurs d'électricité et bâti.

SECTION C : LA CONCEPTION ET L'INSTALLATION DU SYSTEME PHOTOVOLTAIQUE (CHAPITRES 9 A 16)

Guide de conception du système photovoltaïque, depuis l'analyse de la charge et le dimensionnement du système jusqu'au choix des éléments, à l'évaluation des considérations financières, à l'essai du système et à son entretien.

Le manuel a été rédigé de façon aussi simple que possible. On suppose tout de même que le lecteur a une certaine connaissance des rudiments de la physique et de l'électricité et qu'il a une certaine expérience technique de la conception, de la caractérisation et de l'installation de systèmes électriques.

Les renseignements donnés ci-après aideront à comprendre les principes de fonctionnement et la conception des systèmes photovoltaïques. Toutefois, ils ne peuvent se substituer à l'expérience et aux connaissances du technicien en conception. Ils visent simplement à aider les ingénieurs en communication, les utilisateurs de dispositifs de télésurveillance et de téléavertissement et les entrepreneurs en systèmes d'alimentation électrique qui servent des marchés reculés.

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SECTION A

PHOTOVOLTAIC SYSTEMS AND APPLICATIONS

INTRODUCTION (SECTION A)

The first two chapters of this manual introduce the reader to solar radiation and the components of a photovoltaic system.

Chapter 1 describes the main components of a photovoltaic system and reviews the current uses of photovoltaic systems in Canada and abroad.

Chapter 2 introduces the reader to solar energy, describing how solar radiation varies from one location to another and between one season and another. It also describes how to estimate the amount of solar energy available at a given site.

CHAPTER 1

PHOTOVOLTAIC POWER SYSTEMS AND COMPONENTS

1.1 Key Components of Photovoltaic Power Systems

Solar cells produce DC electricity from solar energy. Photovoltaic systems contain solar cells assembled together into modules. These modules are connected together to form an array. Arrays are incorporated into the structure of a building or mounted on their own support frame.

If the power produced is only required when solar energy is available, for example, operating a ventilation fan or irrigation pumping, then the regulated power is supplied directly to the load and no battery is required. If the load requires a constant power source, such as for refrigeration, lighting, or a warning device, a battery is used, so that during periods of low or no sunlight, power can still be supplied to the load. The photovoltaic array must be large enough to meet the average load over a given period such as a typical summer or winter day. The battery must store enough energy to meet the load during low or no sunlight periods, after which it is re-charged from the photovoltaic array.

If AC current is required, for example to run a conventional refrigerator, an inverter is used to convert the DC to AC power.

Figure 1.1 shows a schematic of a basic photovoltaic system with battery storage. The photovoltaic array produces electricity only during sunlight hours. The battery charge regulator prevents excess energy being delivered to the battery. Figure 1.2 shows a schematic of a system without battery storage.

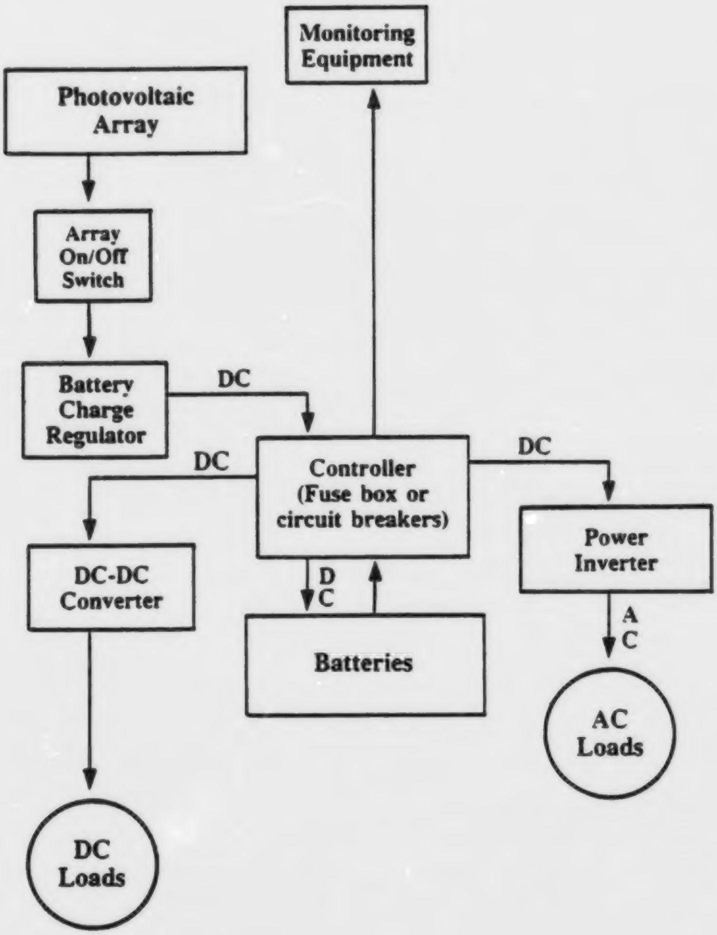

Monitoring Equipment
Photovoltaic Array
Array On/Off Switch
Battery Charge Regulator
DC
Controller (Fuse box or circuit breakers)
DC
DC
DC-DC Converter
D C
Batteries
Power Inverter
A C
AC Loads
DC Loads

Figure 1.1: Basic Photovoltaic Configuration

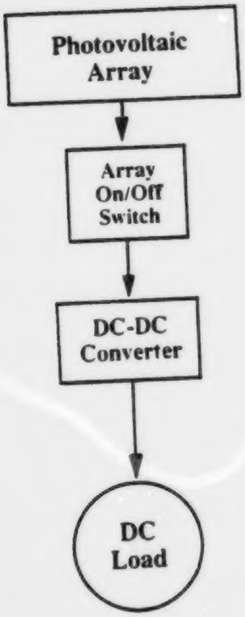

Photovoltaic Array
Array On/Off Switch
DC-DC Converter
DC Load

Figure 1.2: Photovoltaic System Without Battery Storage

Box: Photovoltaic Arrays:

Arrays consist of several modules or panels connected together electrically in series or parallel and mounted on a building or self standing frame. The array faces south (or north in the southern hemisphere) and is usually tilted at an angle to the horizontal approximately equal to the latitude of the site plus or minus 15° depending on the application. This maximizes the solar energy collected during the year and reduces excess solar energy produced in the summer.

Arrays must withstand wind loads and other extreme weather conditions. They must also be protected from damage due to current surges.

Box: Batteries

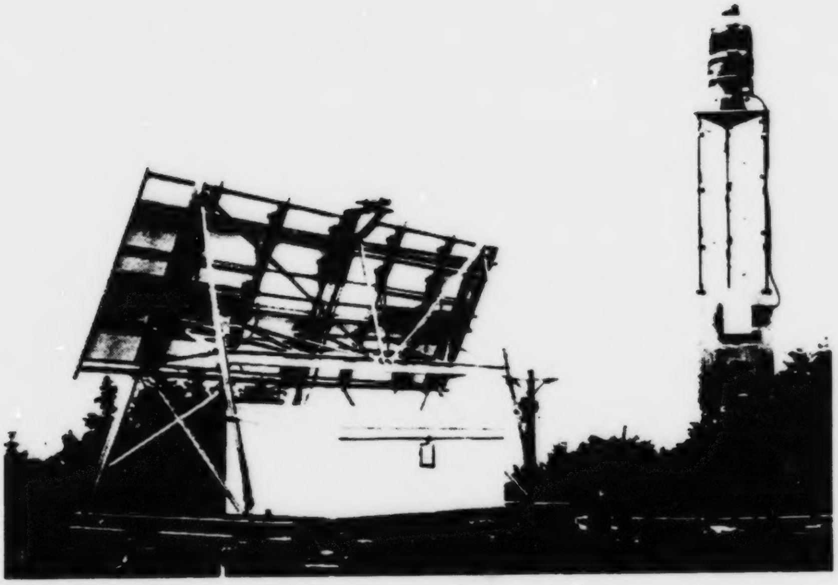
Batteries used in photovoltaic systems must be capable of repeated discharge and recharge without loss of power or damage. The most common types used are lead calcium or lead antimony batteries. Lead calcium batteries are used in "shallow cycle" discharge applications where less than 15% discharge occurs each cycle. Lead antimony batteries are used in "deep cycle" applications where there is up to 80% discharge per cycle. Nickel-cadmium (ni-cad) batteries are also sometimes used, particularly where there are extreme ambient temperature changes. Battery systems are usually sized to provide a period of system autonomy between a few days to 3 weeks. Batteries are usually rated in ampere-hours (Ah). A 24 Ah 12 volt battery will store 24 times 12 = 288 watt hours of electricity at 25°C.

Box: Costs

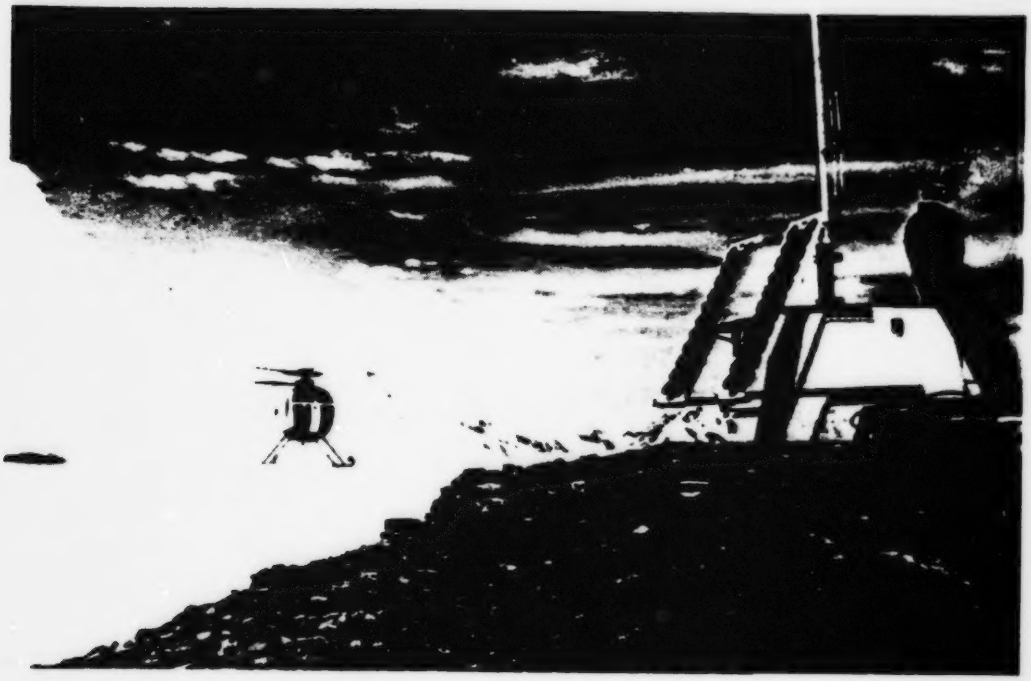
A typical 1989 cost breakdown for a 1 kW photovoltaic system is as follows:

1 kW Photovoltaic Array:	$8,000
2000 Ampere hour Battery:	$6,000
Inverter:	$5,000
Other Components:	$1,000
Installation:	$5,000
	$25,000

The system would be expected to last at least 20 years with battery replacement every 7 years.



Airport Beacon Application



Mountain Top Communications Applications

1.2 Autonomous Photovoltaic Systems

In most current applications, photovoltaic systems provide electrical power without a back up or auxiliary power source. The system array and battery pack meet all load requirements under all solar conditions. The most common applications of this type include radio repeater stations, warning devices such as buoys and navigation lights, electric fencing, and remote lighting and refrigeration. Other applications include water pumping for cattle and irrigation, ventilation fan operation and cathodic corrosion protection.

In most of the above applications the photovoltaic power system is as in Figures 1.1 or 1.2, containing an array, power conditioning equipment and battery storage.

1.3 Hybrid Systems

Electrical requirements in some remote applications are quite large. A remote satellite receiving station or remote lodge off the power grid will usually have a diesel generator supplying AC power to a number of loads. Photovoltaic systems can reduce diesel fuel use and the maintenance requirements on the diesel generating set.

There are two types of photovoltaic/diesel hybrid systems. In the first, DC electrical power from the photovoltaic system is usually converted to AC power using an inverter and supplied directly to the load. Solar electricity is produced only during sunlight hours and the diesel system provides the power at other times or when there is insufficient solar electricity. There is no battery storage and power conditioning equipment protects the photovoltaic array from reverse discharge. The second, and rapidly becoming the most common type of hybrid system is shown in Figure 1.3. Here the photovoltaic system is used to charge a battery pack which powers the load. When the photovoltaic power is insufficient to keep the battery charged, the diesel switches on and rapidly brings the battery up to full charge before switching off again. This intermittent "cycle charge" diesel system can result in much more efficient use of a diesel engine.

Photovoltaic systems are also sometimes combined with other power sources such as wind generators or small hydro systems. Since all are either intermittent or low output power sources, a battery system is usually required as in Figure 1.1.

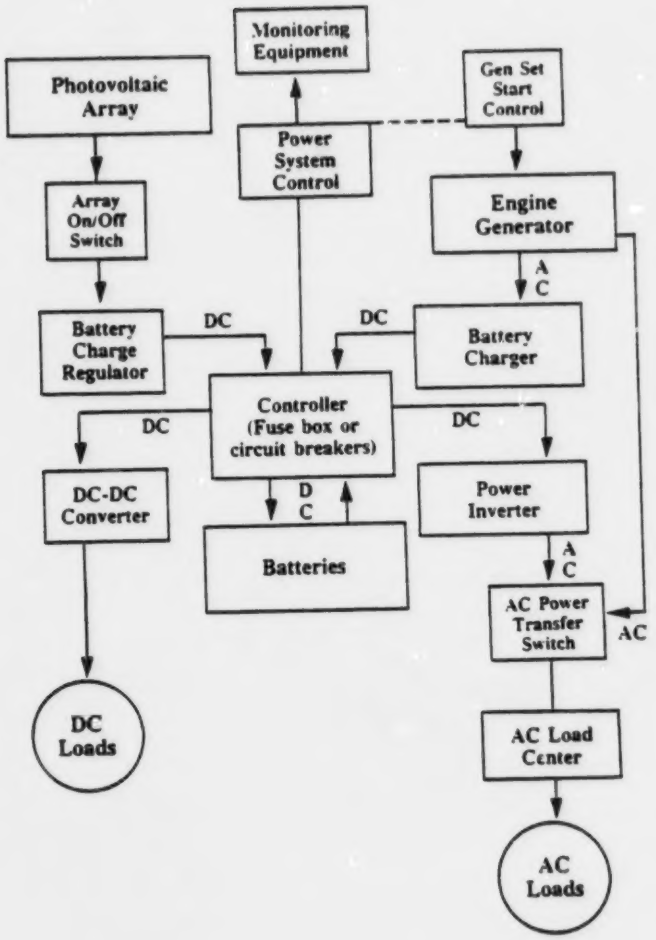
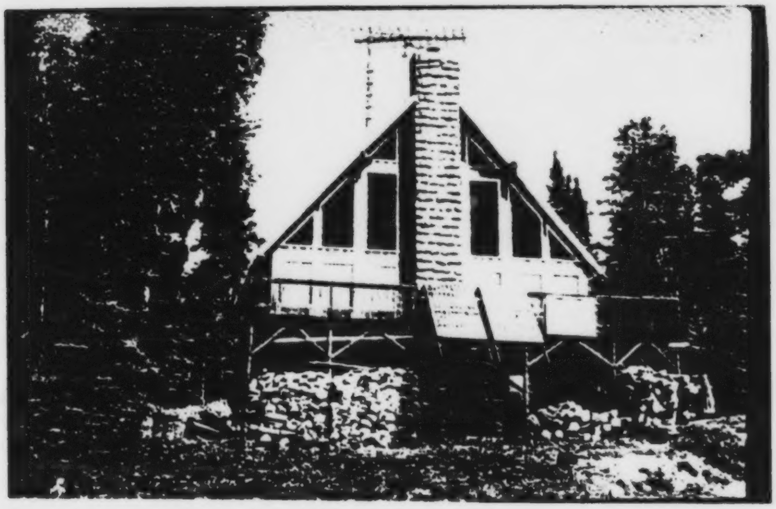

Monitoring Equipment
Photovoltaic Array
Gen Set Start Control
Power System Control
Array On/Off Switch
Engine Generator
AC
Battery Charge Regulator
DC
DC
Battery Charger
Controller (Fuse box or circuit breakers)
DC
DC
DC-DC Converter
DC
Power Inverter
Batteries
AC
AC Power Transfer Switch
AC
DC Loads
AC Load Center
AC Loads

Figure 1.3: Hybrid System with Intermittent Charge Diesel Generator



Remote Lodge Application

1.4 Grid Connected Systems

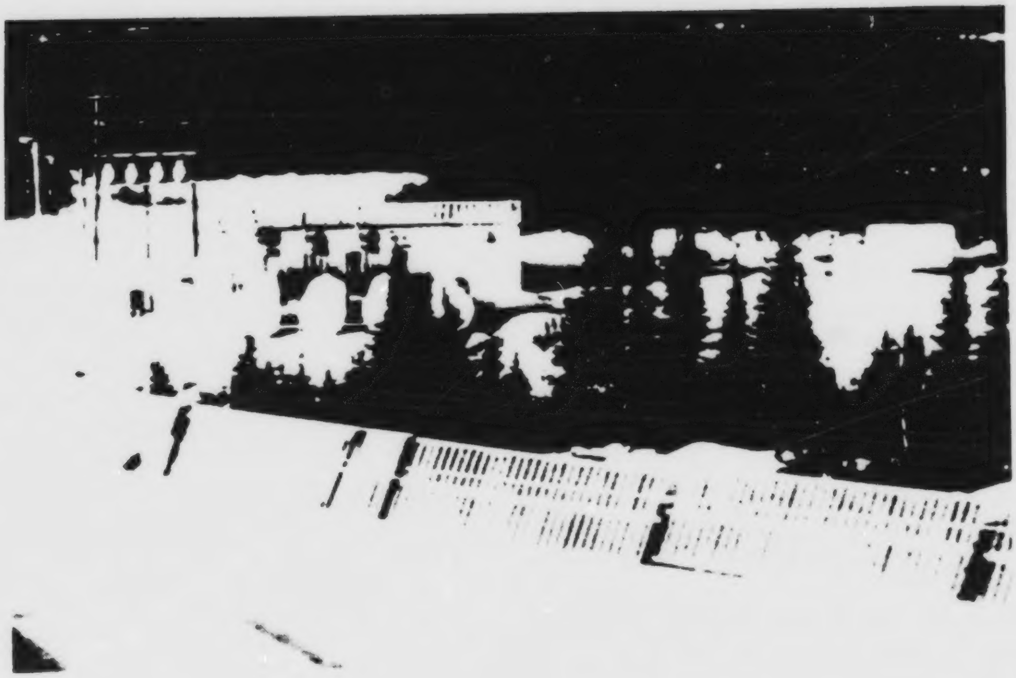
Photovoltaic systems are also used to supply electricity directly into a regional or community power grid. The system feeds power into the grid in the same way as larger conventional thermal, hydro, or diesel generating stations, except that power is produced only during sunlight hours. The DC output from the photovoltaic array is converted to AC power and linked to the grid in the same way as in Figure 1.2.

Grid connected systems can also be interactive -- with the system supplying power to a load and the grid when solar energy is available, and drawing power from the grid to meet the load when there is insufficient solar energy.

In grid connected applications, photovoltaic systems must compete against the cost of the conventional fuel or energy source used to supply the grid. Even in remote communities in northern Canada that have their own community power grid, electricity is supplied from large multiple diesel generating sets operated by the provincial or territorial utility. Photovoltaic power systems are not yet perceived to be cost-effective under most of these conditions.

In parts of the United States where electricity prices are higher and in many other countries where conventional fuel prices are high, grid connected photovoltaic systems are used more widely, however. Photovoltaic systems are particularly cost-effective when the utility load and solar resource profiles are well matched. In California, for example, three solar utilities using between 1 and 4 MW photovoltaic systems, supply electricity to the state grid. Over 100 MW of photovoltaic power is planned for the early 1990s.

In Canada, grid-connected photovoltaic power systems are being evaluated in Northern Ontario. Ontario Hydro operates a 10 kW test system at Big Trout Lake linked to the community's 250 kW diesel generated power grid.

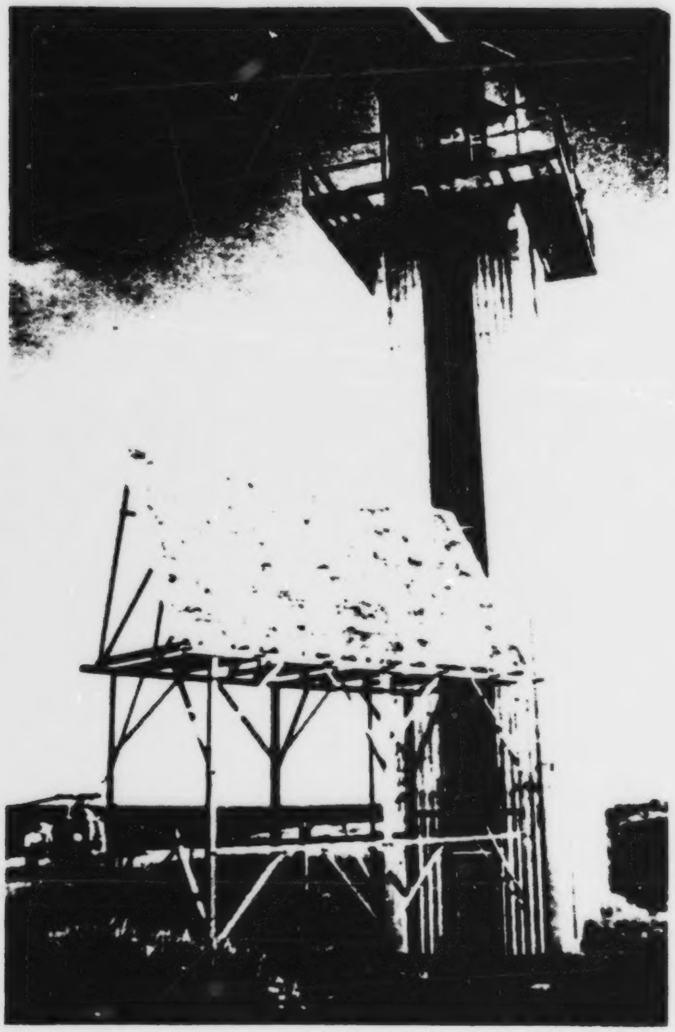


Remote Grid Application

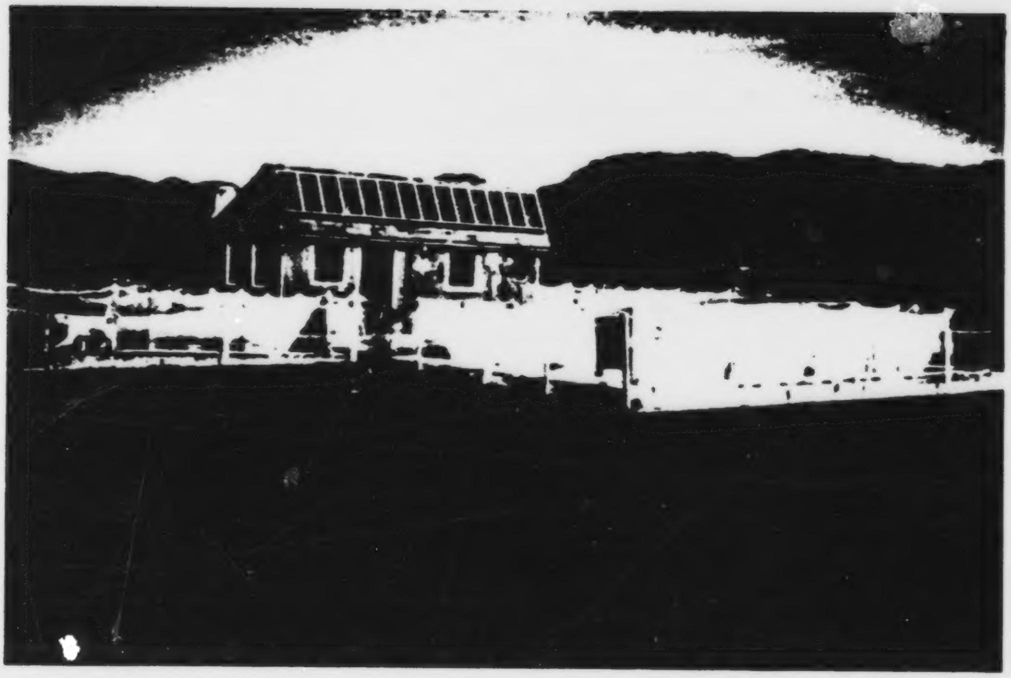
1.5 The Stand-Alone Advantage

Photovoltaic systems are most effective at remote sites off the electrical grid, and in locations where access is by air only, especially if access is limited to helicopters. Their high reliability and low servicing requirements, also make them ideal for applications at other unattended sites. For these reasons, the primary applications for photovoltaics are small electric loads in remote locations. The most cost-effective applications are those with very low power requirements such as warning devices and low-power radio repeaters, or those where no battery system is required, such as water pumping.

Table 1.1 provides a summary of stand-alone applications of solar photovoltaic systems. In many of these applications, PV systems are used to provide all power requirements, with or without battery storage depending on the load. In others, PV systems are used in combination with a conventional power source such as a diesel generator. These "hybrid" systems are found more frequently in larger applications such as water pumping, combined lighting/pumping/refrigeration, or community power systems.



Coastguard Navigation Application



Aquaculture Application

TABLE 1.1

STAND ALONE PV APPLICATIONS

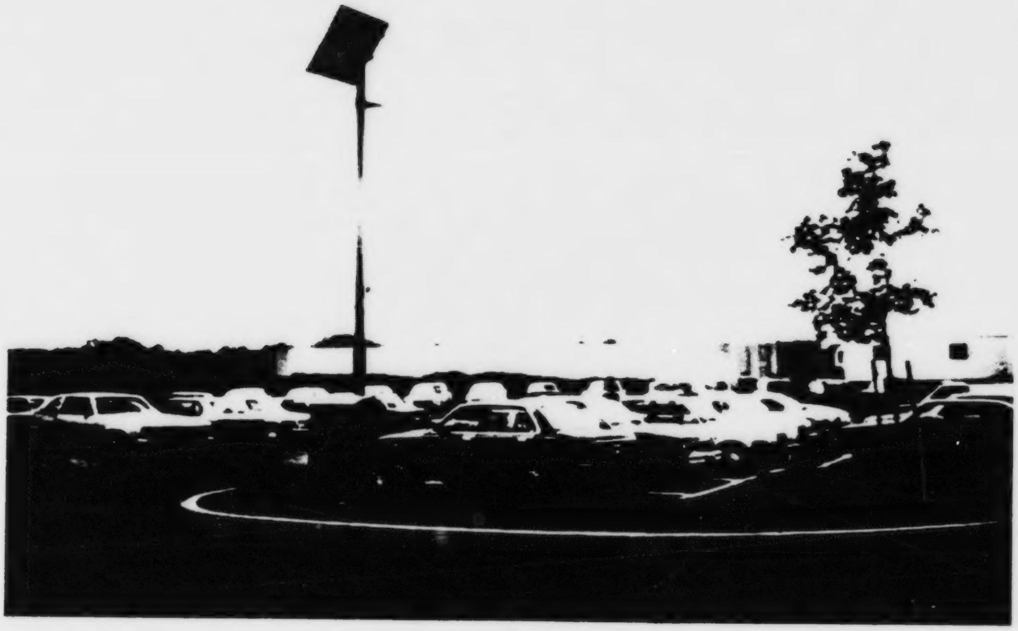
Application	Examples	Types of User	Design Capacity Range (Peak Watts)
Communications	Radio repeaters Telemetry Radio/TV broadcast	Telecommunications Carriers Oil, gas, & pipeline companies Forest/mining companies Radio/TV/Cable companies	40 to 2000
Monitoring and Sensing	Meteorological data logging Remote monitoring Traffic counters Level indicators	Government weather & forests services Oil, gas, & pipeline companies Government environment & transportation agencies	5 to 100
Marking and Warning	Visual navigation aids Radio navigation aids Hazard lighting Runway lighting	Coast Guard Seaway, ports & harbour authorities Petroleum companies Government highway & transportation agencies Department of Defence	10 to 2000
Water Pumping	Irrigation Stock watering Community water supply	Farmers & ranchers Remote communities Rural villages Extension services	50 to 2000

TABLE 1.1

STAND ALONE PV APPLICATIONS

(Continued)

Application	Examples	Types of User	Design Capacity Range
Corrosion Protection	Cathodic protection of pipelines, wells, bridges underground tanks, docks, etc.	Oil, gas, & pipeline companies Departments of transportation	4 to 4000
			(Peak Watts)
Lighting	Highway pole lighting Signs and billboards illumination Security lighting Community clinic or school lighting Recreational lighting	Depts. of highways & transportation Railways Remote communities Remote recreational or industry camps Remote residences Rural villages	5 to 5000
Refrigeration	Medical (vaccines, etc.) Agricultural (vaccines, etc) Recreational	Remote clinics Cattle stations Recreational vehicles Remote camps Remote communities Remote residences Rural villages	5 to 1000
Direct Drive	Ventilation fans Solar tracking devices Solar system pumps	Recreational vehicles Solar system companies	5 to 500
Direct Electricity	Electric fencing	Farmers and ranchers	5 to 100
Multiple Use	Appliances/lighting ventilation/ pumping	Remote residences Remote lodges Rural village services	100 to 5000



Integrated Lighting Application

1.6 Examples of Cost Effective Electric Applications in Canada and Abroad

In Canada:

The most cost-effective uses of photovoltaic power sources in Canada are in remote locations where there is no access by float plane or local airstrip. Before photovoltaic systems were used, batteries, thermo-electric (propane) generators, or diesel generators normally provided power, and the re-charged batteries or fuel were flown in by helicopter. Photovoltaic systems reduce fuel consumption, but most of all eliminate all but one or two occasional flights per year for maintenance.

Examples of these small cost-effective applications are coastal or hill top radio repeaters, warning beacons on hills around airports, and weather monitoring instruments.

Photovoltaic systems are also cost-effective in situations where several small power systems are required, for emergency phones or lights along highways without a power line, or electric fencing for remote ranches and farms. These applications would normally require frequent battery changes using a truck or tractor.

Under some conditions photovoltaic systems are also cost-effective in larger applications where they reduce fuel consumption and maintenance costs in diesel generators. In many remote lodges and larger communications facilities in northern Canada and coastal areas, diesel fuel must be trucked or flown in 45 gallon drums. Photovoltaic/diesel hybrid power systems can cost-effectively reduce the number of fuelling trips and increase the time between maintenance calls.

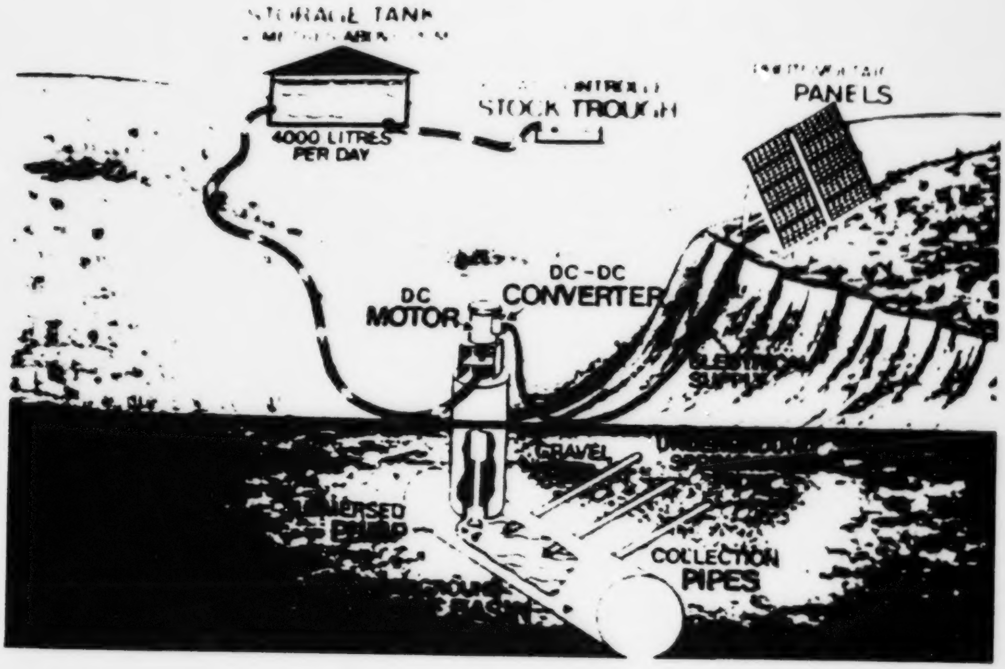
Abroad:

Photovoltaic systems are being used for small remote applications in all parts of the world. In countries with high fuel costs and a good solar resource, however, it becomes cost-effective to use photovoltaics in larger applications, and in countries where many towns and villages are not served by an electricity grid, the potential for their use is even higher. In the United States, Japan, Australia, India, the Middle East and other industrialized countries with good solar insolation levels, photovoltaic systems are finding many new applications.

The most cost-effective uses for photovoltaic power systems in the Third World are for lighting, vaccine refrigeration and communications in rural clinics, schools and community facilities, and where conditions are right, for water pumping. (see sidebar)

It must be remembered, however, that in Third World countries, most rural villages have no source of electricity because there are no national or local resources. Cost-effectiveness means nothing if there is no capital to pay for a power system and no local infrastructure to manufacture, distribute, install and maintain it. Photovoltaics will become common in the Third World only when governments can afford rural health or education services, or villages can generate enough income to purchase and maintain power equipment.

As photovoltaic systems are used more widely and prices come down through research and development and automated production methods, larger applications will become more cost-effective. With the current worldwide concerns about acid rain and the greenhouse effect, solar electricity will play an increasing role in the future.


STORAGE TANK
4000 LITRES PER DAY
STOCK TROUGH
PANELS
DC-DC CONVERTER
DC MOTOR
ELECTRICAL SUPPLY
GRAVEL
SUBMERSED PUMP
COLLECTION PIPES

Water Pumping Application

CHAPTER 2

THE SOLAR RESOURCE

2.1 Solar Energy - A Variable Energy Source

The sun emits visible light at wavelengths of between 0.3 and 3.0 microns. The earth's atmosphere receives this energy at an average rate of 1.37 kilowatts per square metre with a 3% variation as the earth moves further and closer to the sun in its trajectory. The atmosphere absorbs some of this energy, however, and the amount reaching the earth's surface seldom exceeds 1.2 kilowatts (1200 watts) per square metre. The earth's rotation and tilt also means that at any single point on the earth's surface, the energy available varies with latitude and time of the day and year. Finally clouds, fog, and other meteorological features produce daily and hourly variations -- sometimes enhancing the amount of radiation, sometimes decreasing it.

Using solar radiation as an energy source therefore presents us with a unique situation. It is not available on a continuous basis, and we also cannot store or transport it. The designer of any system that uses solar radiation as an energy source must therefore determine how much and when solar energy is available at the required site.

The first concept to understand is what effect the earth's rotation (time of day) and tilt (season of the year) has on solar radiation. Absorption by the atmosphere is lowest when the sun is at its highest point in the sky - due south in the northern hemisphere and due north in the southern hemisphere. This is because the distance the radiation has to travel through the atmosphere when the sun is directly overhead is a minimum. The highest intensity of direct solar radiation occurs at this time, called "solar noon". Because the sun is higher in the sky in summer and the day is longer, however, the total amount of energy received on a horizontal plane is greater in the summer than in winter.

Figure 2.1 illustrates this by showing the trajectories of the sun across the sky at the four seasons of the year.

The effect of latitude is also significant. As one moves away from the equator, summer days are longer, but the sun is lower in the sky at solar noon. Winter days are shorter and the sun at solar noon is even lower. As latitude increases, therefore, both the maximum intensity (at noon) and the total amount of solar radiation falling on a horizontal surface decreases.

As is described below, however, even more significant influences on the solar radiation actually received on the earth's surface are atmospheric effects such as weather and ground cover effects. For example, the intensity of radiation can be reduced by haze and enhanced by snow cover. Winter intensities in cold climates are often higher than those in summer because there is less water vapour in the atmosphere at that time of year.

The amount of solar energy available therefore is more a statistical phenomenon than a geometric one.

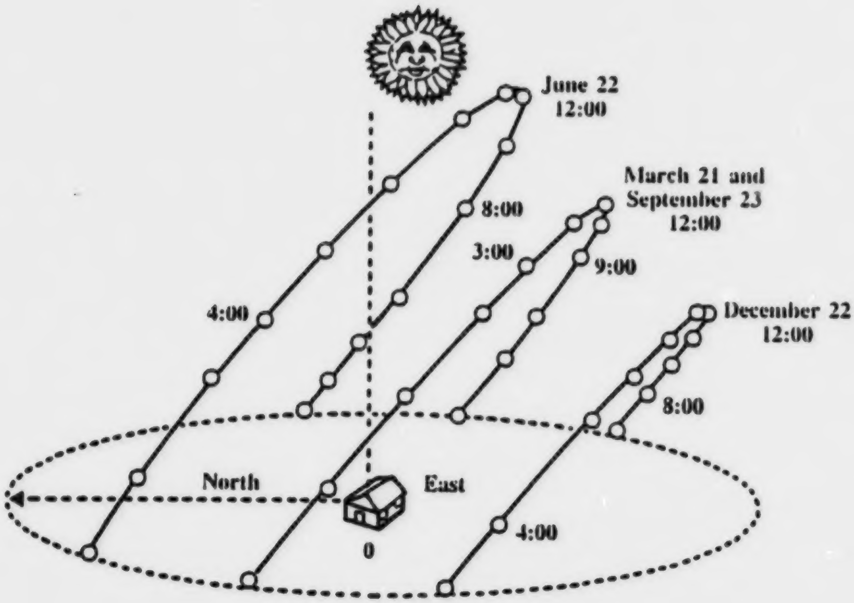

June 22
12:00
8:00
March 21 and
September 23
12:00
3:00
9:00
4:00
December 22
12:00
8:00
North
East
0
4:00

Figure 2.1: Seasonal Sun Trajectories

2.2 Radiation on a Tilted Surface

Figure 2.2 shows how the intensity of the solar radiation or a flat surface is higher when it is tilted towards the sun. The maximum intensity occurs when the flat surface is perpendicular to the suns' rays.

If a flat surface is moved continuously each day of the year so that it is perpendicular to the sun at all times, the total amount of solar energy falling on the surface is a maximum. If the flat surface is fixed, the amount falling on the surface will be lower, because most of the time the sun will be striking it at an angle.

Figure 2.3 shows the effect of tilt angle on the month-to-month radiation falling on a flat surface at a latitude of 45°. It shows that at a tilt equal to about 60° from the horizontal, the flat surface receives about the same amount of solar energy throughout the year. The maximum annual radiation occurs when the surface is tilted at an angle equal to the latitude.

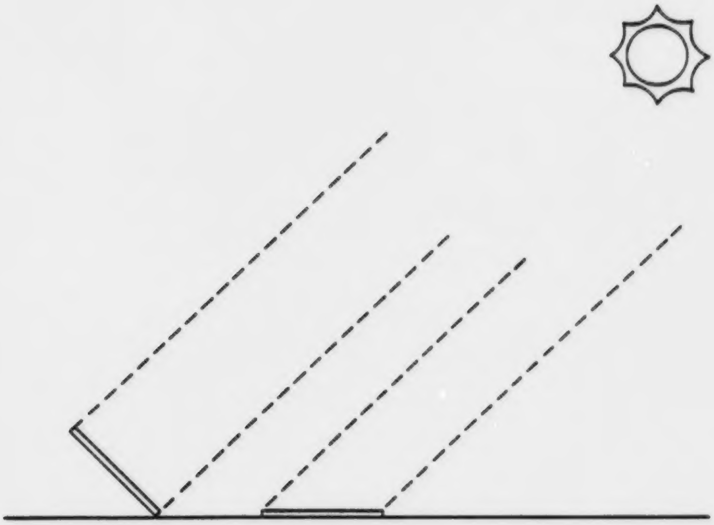


Figure 2.2: A Tilted Surface Receives More Radiation Than A Horizontal One

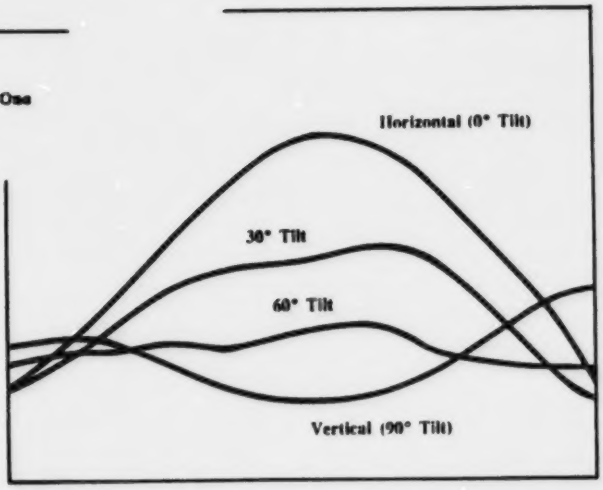


Figure 2.3: Effect of Tilt on Month-to-Month Radiation in Middle Latitudes

2.3 Effect of Weather

Because weather is unpredictable, it is difficult to predict the actual amount of solar radiation available at a given site. Weather has several effects on the amount of radiation available and the direction from which this radiation comes.

- Water vapour and airborne particles reduce the amount of direct solar radiation reaching the earth's surface from the sun by reflecting or absorbing it - over and above the reduction caused by the atmosphere itself.
- Cloud, haze, and the atmosphere itself also scatter light so that a portion of the radiation appears to come from all parts of the sky and not directly from the sun. This scattered light is called diffuse radiation.
- Seasonal ground covers such as ice and snow reflect solar radiation, therefore increasing the amount falling on a flat surface -- particularly a tilted surface.

2.4 Effect of Local Features

Shading by topographical features such as hills or mountains or by buildings and trees can also reduce the amount of solar radiation falling on a flat surface - particularly on tilted surfaces and particularly in winter when the sun in low.

Various topographical features such as water bodies, ground covers such as fields, sand, tree cover, and urban landscapes also reflect varying amounts of solar radiation. This can actually increase the amount of radiation falling on a flat surface -- particularly if it is tilted.

2.5 Units of Solar Radiation

Solar irradiance is the intensity of solar radiation received on a surface at a given time. It is usually expressed in watts per m^2. As described in Section 2.1 above, irradiance varies from zero at sunrise to a maximum at solar noon.

Insolation is the amount of solar energy received on a surface over a period of time. It is usually expressed in units of kilowatts-hours per square metre (Kwh/m^2), "peak sun hours", megajoules per square metre (MJ/m^2) or Langleys (L), for the given period such as a day or hour.

$$1 \text{ Kwh/m}^2 = 1 \text{ peak sun hour} = 3.6 \text{ MJ/m}^2 = 0.0116\text{L}$$

Daily values of insolation are usually presented as monthly averages for different latitudes, tilts, and specific locations (to allow for differences in weather effects). The most common measure of insolation used is "peak sun hours". This is the equivalent number of hours per day when the solar irradiance averages 1000 watts/m^2. A value of 6 peak sun hours, for example, means that the insolation received in one day is the same as if the sun had shone for 6 hours at 1000 watts/m^2. Peak sun hours is a useful measure when sizing photovoltaic systems since they are usually rated in peak watts.

There are four types of insolation:

- *Direct insolation* is the radiation received directly from the sun and is also sometimes called beam radiation.

- *Diffuse radiation* is the radiation received from other parts of the sky as a result of atmospheric scattering of sunlight.

- *Reflected insolation* is a radiation received by reflection from the ground or surface features.

- *Global radiation* is a measure of all radiation received including reflection from the ground or other surface features.

Figure 2.4 shows typical Canadian mean monthly values of daily direct and global radiation in MJ/m^2 day on a south facing surface at three tilt angles.

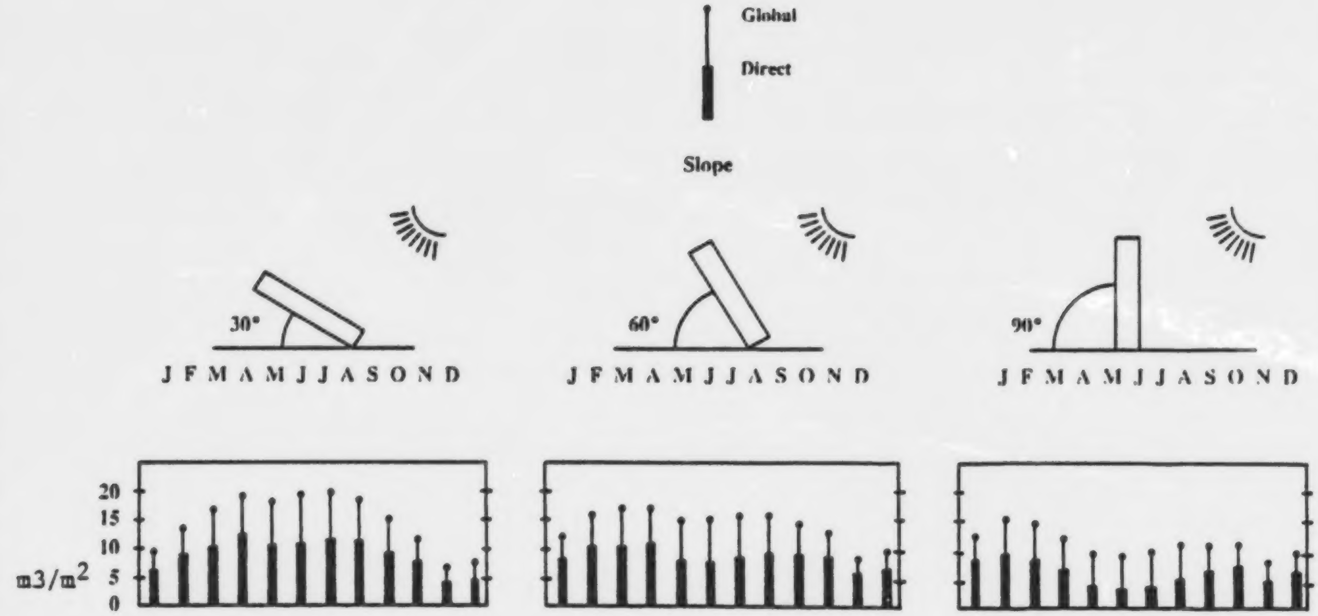


Figure 2.4: Typical Measured Global and Direct Radiation at Different Tilt Angles in Southern Canada

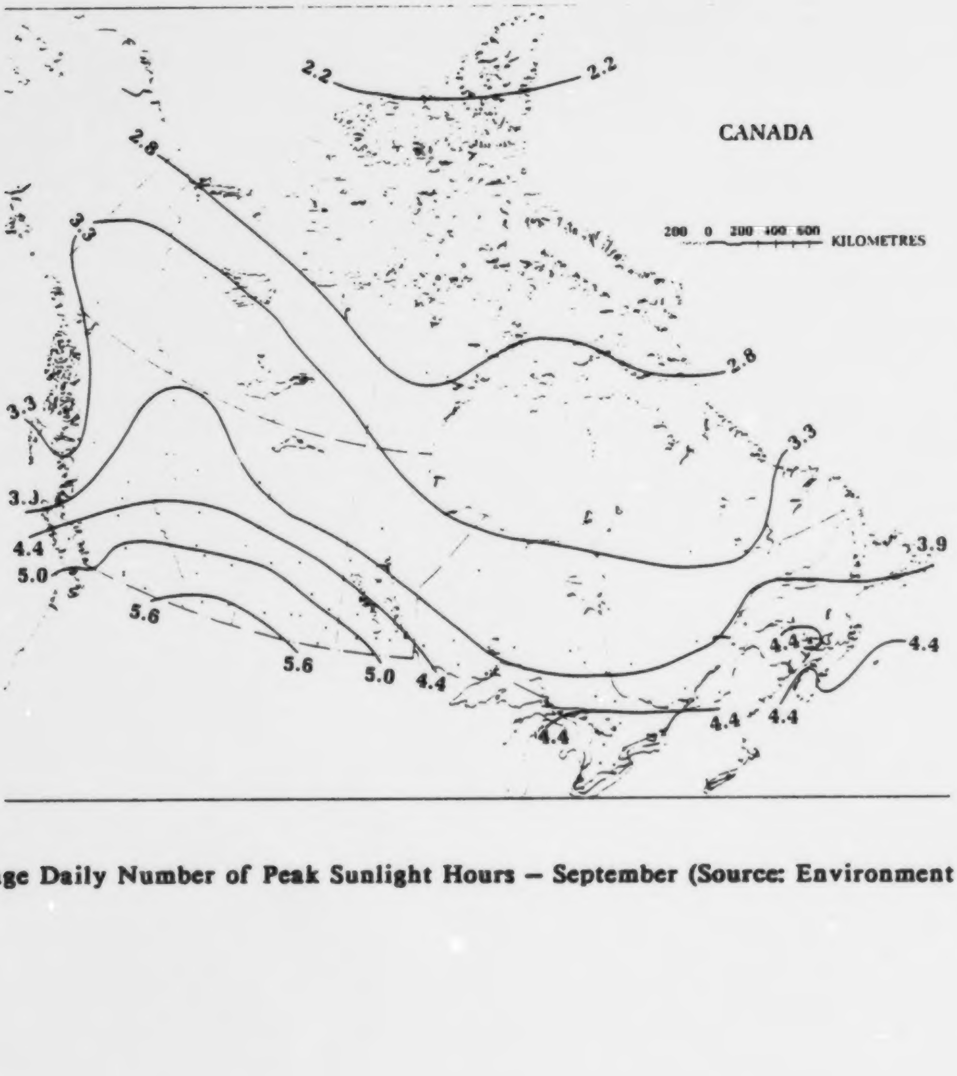
2.6 How to Estimate Energy Available

The Environment Canada publication "Solar Radiation Data Analysis for Canada 1967-1976", lists global, direct and diffuse insolation (in MJ/m^2) measured at 129 stations across Canada using an instrument called a pyranometer. Average daily values and average radiation received between 9:00 a.m. and 3:00 p.m. are provided for each month of the year for horizontal surfaces and surfaces tilted at latitude, latitude plus 15°, and 90° (vertical). Divide MJ/m^2 by 3.6 to obtain Peak Sun Hours.

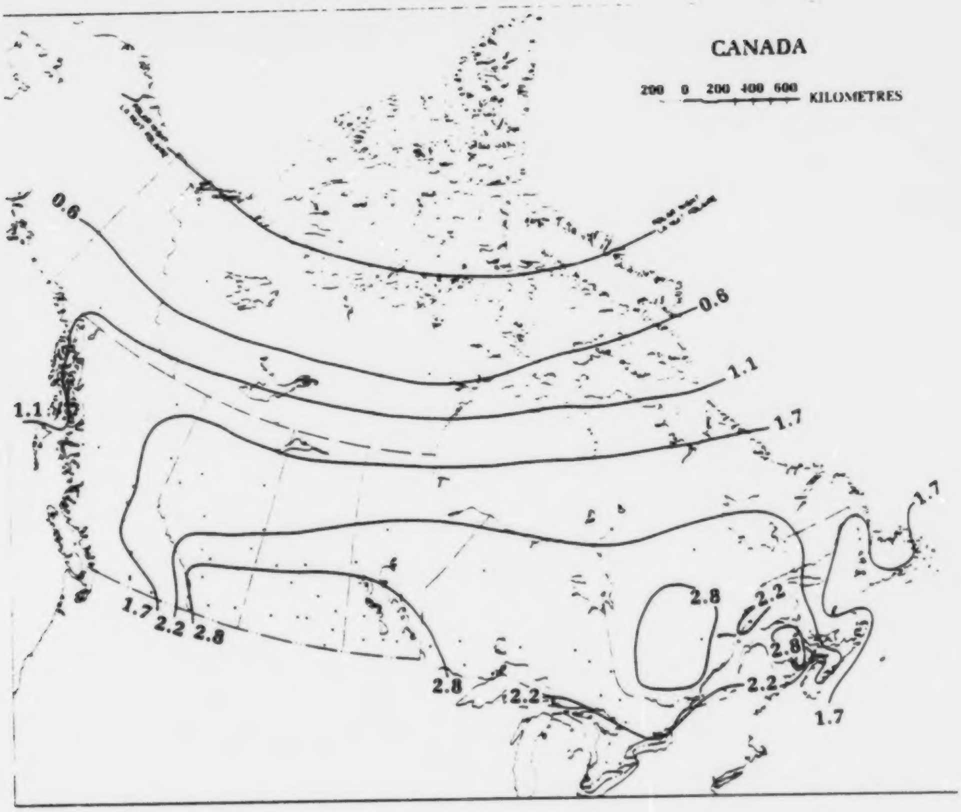
Appendix 1 contains average global daily insolation at tilts of latitude and latitude plus 15°, for 14 of the 129 stations, and contour maps for the whole country in MJ/m^2. Two maps showing peak sun hours in September and December (typical design months) are shown below. Environment Canada also provides computer tapes and diskettes giving hour by hour insolation at each of the measurement sites for more accurate estimates and system performance simulation.

In most parts of Canada, use insolation data from the station nearest the proposed site, or interpolate between two or three stations in the vicinity. In mountainous regions or regions where fog and other local weather conditions occur, it may be necessary to make some corrections to the station data. "Fraction of Bright Sunshine" data can also be used to estimate insolation levels in locations that are not close to a solar radiation measurement site. Temperature and Hourly Bright Sunshine data at 320 locations across Canada is available from Environment Canada Canadian Climate Normals.

Section C of this handbook contains worksheets for estimating average daily insolation values for system design purposes from the above sources.


CANADA
200 0 200 400 600 KILOMETRES
2.2
2.2
2.8
2.8
3.3
3.3
3.3
3.3
3.9
4.4
4.4
4.4
4.4
4.4
4.4
4.4
5.0
5.0
5.6
5.6

Average Daily Number of Peak Sunlight Hours – September (Source: Environment Canada)


CANADA
200 0 200 400 600 KILOMETRES
0.6
0.6
1.1
1.1
1.7
1.7
1.7
1.7
2.2
2.2
2.2
2.2
2.8
2.8
2.8
2.8
1.7

Average Daily Number of Peak Sunlight Hours – December (Source: Environment Canada)

SECTION B

COMPONENTS OF PHOTOVOLTAIC SYSTEMS

INTRODUCTION (SECTION B)

The next 6 chapters of the manual describe each of the key components of a photovoltaic system in more detail. They also provide all the information required to select components for different system configurations and types.

Chapters 3 and 4 describe photovoltaic modules and arrays, while Chapter 5 covers array support structuring.

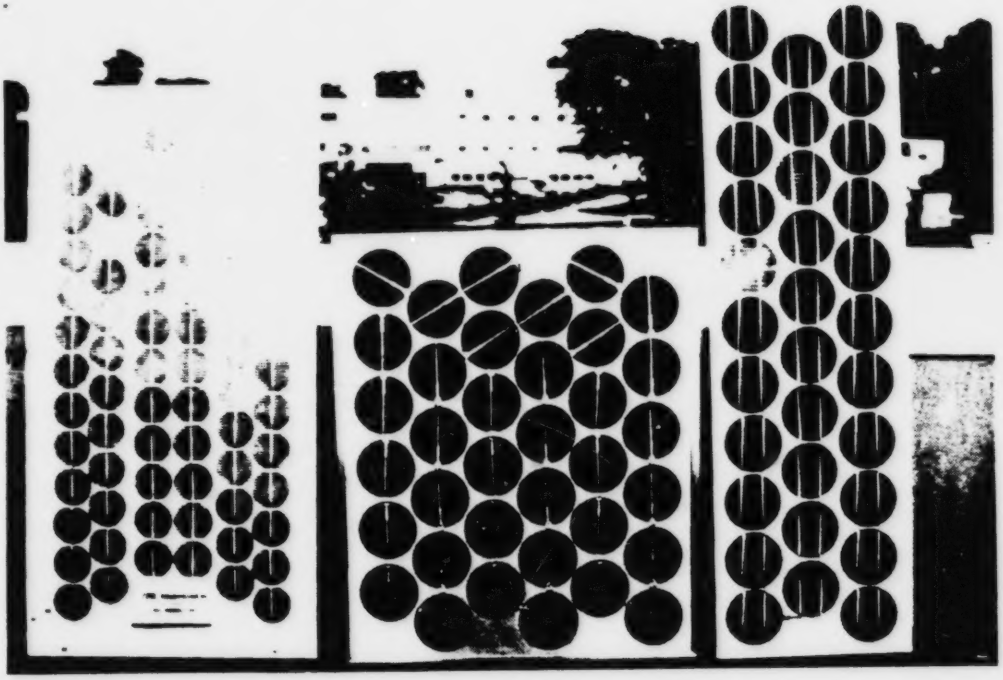
Chapter 6 describes the different types of batteries that are used for energy storage in photovoltaic systems, drawing particular attention to factors affecting battery performance. Chapter 7 covers power conditioning equipment including voltage regulators and inverters.

Chapter 8 describes auxiliary power systems used with photovoltaic systems.

CHAPTER 3

PHOTOVOLTAIC MODULES

Photovoltaic modules are the basic building blocks of any photovoltaic system. Each module contains up to 40 solar cells permanently wired together in series and parallel to form a single electric power unit rated at between 35 and 50 watts. The unit is packaged together so that the cells are protected from the environment while permitting sunlight to reach the active surfaces of the cells. This chapter describes how a solar cell works and how modules are constructed. It also describes how cell and module performance is characterized.



Photovoltaic Modules

3.1 How a Solar Cell Works

A photovoltaic or solar cell is a solid state device that converts sunlight and electro-magnetic radiation into electricity. Solar cells are made from semi-conductor materials such as silicon or gallium arsenide which react in a unique way when exposed to light.

When light is absorbed by a solid conducting material such as a metal, it excites free electrons in the material's atomic structure. The electrons remain combined with the individual atoms, however, and most of the absorbed energy is converted into heat. In semi-conductor materials shorter wavelength light (in the visible and ultraviolet regions) causes the electrons to actually break loose from atoms in the material structure, leaving the atoms with a positive charge. Under proper conditions, both the electrons and positive charge can move through the material (in opposite directions) and contribute to an electric current. A photovoltaic cell is designed so that these free electrons are prevented from re-combining with atoms having a vacant electron site until they have done useful work by being passed through an external circuit as an electric current.

The force that drives the electrons and positive vacancies or "holes" through the semiconductor and the external circuit is provided by an internal electric field which is created by joining together two parts of the same semiconductor (or of different semiconductors) that contain different types of impurity. Such a device is called a p-n junction, where p indicates conduction by positive carriers (holes) and n indicates conduction by negative electrons.

Three conditions are therefore necessary for a current to flow from a solar cell:

- light must fall on the cell to free the charge carrying electrons.
- there must be a means of moving these free electrons across a junction to keep them at one end of the cell
- an external circuit is required so that a current of free electrons may flow

In an electrical circuit a photovoltaic cell acts as a current source. This means that under load conditions, a solar cell is capable of supplying varying voltage, power, and energy at nearly constant current. By comparison, a battery is a voltage source supplying varying current, energy and power at constant voltage.

A solar cell like a battery, is a source of direct current (DC) power.

3.2 Solar Cell Efficiency

Only part of the light energy falling on a solar cell is converted into electrical energy. The remainder is lost by reflection from the cell surface or in the form of heat. Some of the losses are due to physical processes inherent in the conversion process. Careful cell design can minimize others.

Optical Losses:	Untreated surfaces can reflect up to 35% of the light falling on it. Surface treatments such as texturing or colouring can reduce this to about 5%.
Conversion Losses:	Losses in the conversion of the energy of light to electrical energy occur because: 1) Some of the sunlight (infrared) does not have sufficient energy to release electrons and passes through the semiconductor to be absorbed or reflected by the base electrode. 2) Light at the other end of the solar spectrum (visible and ultraviolet) has more energy than is required to release electrons and the excess is dissipated as heat produced as a result of collisions. These two effects limit the maximum theoretical efficiency of single p-n junction solar cells to between 20 and 30%. Smaller effects due to the recombination of electrons and holes at defects and impurities cause further reductions in efficiency.
Resistance Losses:	The base material of the cell, the surface layers of the cell, and the circuit connections all provide a resistance to current flow, lowering the voltage and therefore encouraging recombination of electrons.
Self Shading:	The electrical contacts on the surface of the cell reflect light and shade parts of the cell material directly under them.
Temperature Losses:	Some solar cells materials are more appropriate for use at high temperatures. In general performance degrades as the ambient temperature increases.

In general, the above losses reduce solar cell conversion efficiency to between 5% and 30% depending on the material, cell design, and its operating temperature.

3.3 Characteristics and Performance

The output of a solar cell varies in almost direct proportion to the intensity of light falling on the cell.

A cell is characterized by its nominal voltage (V_{mp}) and the peak power (V_{mp} times peak current I_{mp}) in watts under standard light and temperature conditions. These standard conditions are 1000 watts/m2 of light with a spectrum similar to sunlight received on the earth's surface (after absorption by the atmosphere). This output is called the peak watt rating of the solar cell.

The power output of a cell in watts at voltage V and current I amps, is equal to V times I. The relationship between V and I is governed by the resistance of the load placed on the cell.

$P = V * I$ (Power Law)
$V = I * R$ (Ohm's Law)

Where V = Electromotive force (volts)
P = Power (watts)
I = Current (amps)
R = Resistance (ohms)

When the load resistance is very small, then the voltage is also very small and the cell is considered to be short circuited. When V=0 the current is equal to the "short-circuit current" I_{sc}. As resistance increases, the voltage also increases until it reaches the "open-circuit voltage" V_{oc} when no current flows. Figure 3.1 shows the I-V relationship of a solar cell.

At each point on the curve the power output is equal to V times I, the peak output occurring at a point where V times I is a maximum (V_{mp} and I_{mp}).

Figures 3.2 and 3.3 show how the I-V curve changes with light intensity and temperature, and also indicates the locus of the maximum power point. Voltage decreases by about 2.2 mv per degree C as temperature increases.

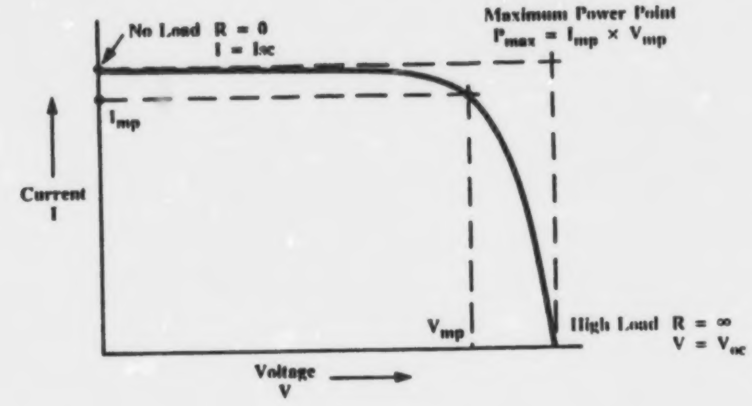


Figure 3.1: Current-Voltage Relationship in a Solar Cell

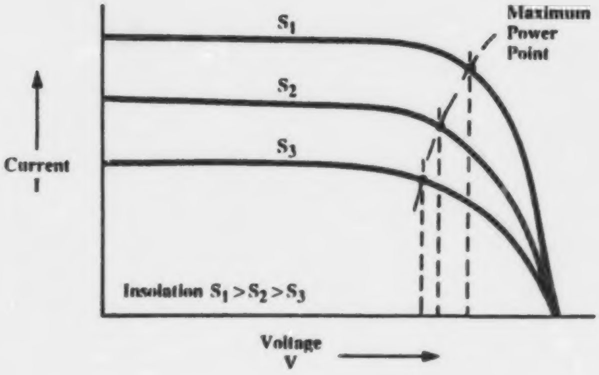


Figure 3.2: I-V Curve Variation with Light Intensity

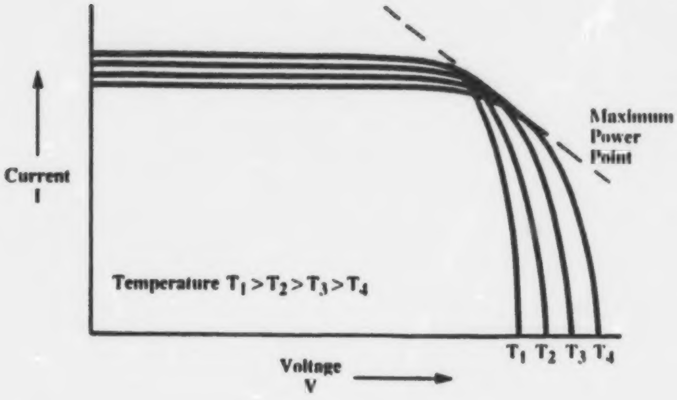


Figure 3.3: I-V Curve Variation with Temperature

3.4 Types of Materials Used in Solar Cells

The most common semi-conductor material used in photovoltaic cells is single crystal silicon. Other materials include polycrystalline silicon, amorphous silicon, gallium arsenide, cadmium telluride and copper indium diselenide.

Single Crystal solar cells are usually made by first producing a single crystal ingot doped with boron then slicing the ingot to produce 4" disc-shaped or square wafers about 250 to 500 microns thick. Individual cells are produced by diffusing phosphorus into the p-type silicon wafer to create an n-type surface region. An electrical contact in the form of a grid is deposited on the side of the wafer exposed to sunlight, and a solid contact on the otherside.

Polycrystalline silicon is made up of grains of crystalline silicon. Square or rectangular cells about 30 to 50 microns thick are cut from cast ingots of the material. Costs are slightly lower than those of single crystal cells and the cells are more conveniently shaped. Efficiencies are slightly lower however, because impurities tend to collect at grain boundaries.

Amorphous silicon differs from crystalline material in that there is no orderly structure to the atoms. Its advantage is that all the light energy is absorbed in a thin surface layer and therefore the cell is very thin. Cells are made by depositing layers of silicon 0.5 to 1.5 microns thick onto a substrate, using automated equipment. The efficiency of conversion, however, is lower than in crystalline or polycrystalline silicon cells. Amorphous silicon cells are widely used in low cost applications such as watches and calculators.

Gallium arsenide is a compound semi-conductor which also absorbs sunlight in a thin surface layer. Its optimum operating temperature is higher than silicon making it suitable for use in photovoltaic arrays where reflectors concentrate sunlight onto the cell. It also has one of the highest potential conversion efficiencies, approaching 22% in practice, with a theoretical maximum over 30%. This compares with a 22% maximum for crystalline silicon cells. Gallium arsenide cells are considerably more expensive than silicon cells and are used mostly in concentrating modules or arrays (see Chapter 4).

Several other photovoltaic materials are under development and the efficiency of the above cell types are gradually improving through changes in materials processing and cell design.

3.5 Module Construction

Most commercially available power modules consist of a single series string of 30 to 40 cells. The number of cells in series is traditionally chosen by the module manufacturer sufficient to provide the necessary operating voltage under expected field conditions to charge 12 V lead-acid batteries. The variation in the number of cells needed to produce this voltage is due to slight performance differences among cells, and to the fact that output voltage decreases as the temperature increases (by about 0.5% per degree C), thus requiring more cells under hotter operating conditions to produce the same operating voltage.

Connections between cells within a module must provide reliable conductivity despite the variations in temperature and climatic factors which can deteriorate electrical integrity. Such connections usually are accomplished with flexible sheet metal strips or mesh soldered or welded to the cells. This flexibility allows movement within the module caused by thermal expansion and contraction. Many module designs now include multiple interconnect attachment points to reduce the failure potential caused by cracking or local degradation.

Encapsulation is required to protect the cell from snow, moisture, hailstones and falling branches, while guarding against electrical hazards for the user. The superstrate must provide high optical transmission in order to allow maximum solar radiation to reach the cell, and it must offer low soiling characteristics. In most cases, tempered low-iron glass is the accepted industry superstrate.

The current industry standard for encapsulation involves lamination under pressure and raised temperature. Ethylene Vinyl Acetate (EVA) is used most often as the encapsulating material.

A frame is included for added mechanical strength, and to facilitate ease of mounting. Typically this will be of extruded aluminum, but stainless steel and other materials are also used.

An electrical junction box is usually attached to the back surface of the module. The positive and negative leads from the solar cell string are brought through the back surface of the module and terminated in the junction box at normal screw or quick-connect terminals, facilitating easy connection to other modules or system components via standard wiring. The junction box may also contain other items, most commonly ground connection points and bypass diodes (see Chapter 4). Some modules eliminate the junction box in favour of two pigtails or separate sockets.

By incorporating a lens or reflector, it is possible to concentrate sunlight onto a smaller active cell surface, thereby increasing the output current of the module. The output per square metre of surface exposed to the sun is also increased. Concentrating modules are used primarily in applications where high current is required and are usually incorporated only into arrays which track the sun (see Chapter 4). Concentrator modules concentrate sunlight either on to a line focus (linear concentration) or spot-focus.

3.6 Electrical and Mechanical Reliability and Safety

The electrical and mechanical reliability of PV modules has been well proven and widely accepted. One measure of their reliability can be found in the fact that ten year warranties are commonly available (with a maximum 10% degradation in power output over that time), and 20 years is almost universally accepted as a minimum expected life of a module, a firm indication of their durability. One recent major study measured the probability of module electrical failure at one per 7200 module years, that is, if an installation had 7200 modules, an average of one module could be expected to fail and require replacement annually.

Most module failures are due to the following:

- cracked cells, which may cause an open circuit;
- moisture ingress (into either the module proper or the junction box), which causes corrosion and thus high resistance; or
- fracturing of the glass superstrate (usually from vandalism), which may cause an immediate open circuit, or allow moisture to enter.

There are essentially no safety concerns with individual PV modules. The operating voltage and current levels of modules is sufficiently low that shock hazard is not a serious issue for small systems. However, unlike most other electrical equipment, photovoltaic modules cannot be readily turned off, and this does cause possible hazards when several modules are interconnected at higher voltages (over 50 volts). This issue is dealt with more fully in Chapter 4.

3.7 Module Testing and Certification

Photovoltaic modules testing can be broken down into three categories: performance, safety and reliability/durability. Performance tests measure the electrical output of a module under specified environmental conditions, where the two most important parameters are the level of insolation and the temperature. Safety tests are related to the possible breakdown of the insulation around the power carrying circuitry within the module, and to the integrity of the grounding circuitry. Tests dealing with reliability/durability are the most varied and extensive, and most are environmental resistance tests (e.g. temperature cycling, hailstone impact), although some are related to possible electrical stresses (e.g. hot spot endurance test).

Canadian Standards Association (CSA) has developed a standard (CAN/CSA-F380-M87 "Photovoltaic Modules") for testing and rating modules which incorporates all of the test types mentioned above. ORTECH laboratories in Mississauga, Ontario provide testing services to CSA standards. The Canadian Coastguard has also developed their own purchase specification, which includes a series of tests as well as specific module properties. The International Electromechanical Commission (IEC), Technical Committee (IEC/TC82) is currently developing a series of international standards for PV modules and systems.

Currently, no formal certification of modules is carried out by any agency within Canada.

3.8 Module Performance

The primary indicator of performance of a photovoltaic module is like a single cell, its current/voltage or I-V curve. This curve represents the various possible operating points of the module under specified conditions. As with a single cell, the two parameters upon which module performance is most strongly dependent are insolation and temperature. (**NOTE:** Other factors affect performance, but can normally be regarded as minimal for the purpose of system design.) Convention, now being adopted in formal test and rating standards, is that the "standard" module IV curve is given for a module operating under an intensity of 1000 W/m2 and 25°C cell temperature. 1000 W/m2 is typical of what a module would receive if it were facing directly at the sun on a clear day. 25°C has been selected as a convenient temperature for indoor testing of modules.

System design decisions are usually based on an insolation levels of 1000 W/m2. The concept of "peak sun hours" or "hours of peak sunshine" has evolved to account for the temporal variability of sunlight. A peak sun hour represents the solar energy equivalent to one hour of insolation at a constant level of 1000 W/m2 (which equals 3.6 MJ/m2). Thus three continuous hours at 600 W/m2 would be equal to 1.8 hours of peak sunshine. Using this convention, the design process needs only to be concerned with the module performance at 1000 W/m2.

In general, the cells within a module in the field operate at a temperature of 20-25°C above ambient in sunny conditions because of heating by the sun. Thus it is typical to estimate module performance at about 50 C for design purposes. For estimating field performance of a module, therefore, it is appropriate to take the standard I-V curve and derate the voltage by somewhat more than 10%, while making no adjustment to the current.

3.9 How to Interpret Manufacturer's Data Sheets

Most module data sheets will provide the maximum power point of the I-V curve expressed in peak watts under nominal conditions. However, unless a system includes a maximum power tracker, it will not generally operate at this point. The designer must determine a typical operating point for the system, and then base module output power calculations on this. For battery-based systems, the module operating voltage is usually pegged at the battery voltage, which varies only slightly under normal conditions. For systems which do not have batteries, or where the array is isolated from the battery voltage by power conditioning circuitry, the array operating point can be estimated using the input impedance of the load or power conditioning equipment, as appropriate.

A further caution must be extended when reading data sheets. In the absence of firm standards, there may be slight differences in the test conditions or methods used to determine the I-V curve of a module from one manufacturer to another. Normally these differences will be only slight but try to obtain I-V curves measured by an independent agency. A potentially greater significance should be attached to how representative the I-V curve on the data sheet is of the production modules which will be supplied. The data sheet could be labelled as a "minimum" specification, an "average" curve, or a "typical" curve. If it is labelled as average or typical, read the fine print to determine the degree of variability between modules (e.g. average +/-10%). If the fine print does not clarify the representative nature of the I-V curve, ask the dealer for more information.

In addition to the data sheet, some manufacturers will supply individual performance ratings for each module that they sell. Table 3.1 provides power ratings of several widely used modules.

TABLE 3.1

POWER, VOLTAGE AND CURRENT RATINGS OF TYPICAL PHOTOVOLTAIC MODULES

MODULE	POWER* (WATTS)	VOLTAGE (VOLTS)	CURRENT (AMPS)
Arco M75	50.0	16.0	3.13
Hoxan H-4001	40.1	17.3	2.32
Kyocera LA 361J48	48.0	16.7	2.88
Solarex MSX-60	60.0	17.8	3.37
Solarpac SM-36	37.45	17.09	2.19
Astropower Apc 4044	45.0	17.0	2.65

* At rated voltage

CHAPTER 4

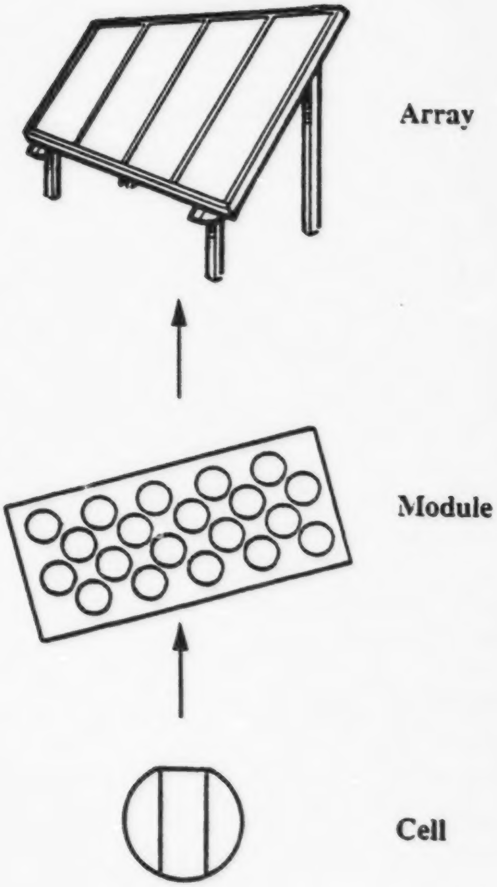
PHOTOVOLTAIC ARRAYS

4.1 Fixed Arrays

A fixed photovoltaic array consists of a number of electrically interconnected photovoltaic modules which safely deliver power to an external device such as a load or a power conditioner. Every array will include module interconnect cabling and a mechanical support structure, and they may include such items as blocking diodes, bypass diodes, test points, fuses, switches, intermediate junction boxes, reflectors, lightning protection devices, and an electrical grounding system. This chapter deals with all of the electrical components of the array. Mechanical support structures are discussed in Chapter 5.

Some larger arrays consist of several identical sections, each independently mounted; in such cases the entire array may be described as an array field, with each independent section termed a sub-array. Some suppliers offer several modules in a prewired assembly called a panel, which is designed to reduce installation labour. Typically a preassembled panel would consist of 4-10 modules, and would be sized small enough that they can be readily handled by one or two persons.

For some applications, arrays may include reflectors mounted at an angle adjacent to the modules. These serve to reflect additional sunlight onto the modules, thereby increasing their power output. Arrays such as these are called termed reflector augmented arrays, or, more often, augmented arrays.


Array
Module
Cell

Cell, Module and Array

4.2 Tracking Arrays

Tracking arrays allow the modules to remain facing directly at the sun as it moves through the sky by automatically adjusting the tilt and/or orientation of the modules. This increases the amount of sunlight striking the modules and enhances their performance. Two-axis tracking is used for modules with a high concentration ratio, and allows the module to remain facing directly at the sun at all times, usually with a very small degree of error (less than 1%). One axis tracking involves a simple rotation on an axle, and allows the modules to track the sun from east to west, but does not permit the array to track the change in elevation of the sun, although the tilt angle of the array may be manually adjusted on a seasonal basis. One axis tracking is normally used for linear concentrating modules (i.e. those modules which concentrate sunlight along a line rather than on a spot), and it may be used to enhance the performance of conventional or augmented arrays.

Fixed arrays cost less to install than tracking arrays, and also require lower maintenance, but tracking arrays provide more energy for the same module area particularly in clear sunny climates. An additional drawback with many tracking arrays is that they will not operate at windspeeds greater than 50 kph.

Because the added capital cost can rarely be justified, fixed arrays are almost always used on smaller systems (less than 500 Wp). Because most of Canada has relatively cloudy weather, fixed arrays have been used for almost all large systems in this country as well.

4.3 Array Orientation and Tilt Angle

Array orientation refers to the direction in which a fixed array faces and is almost always due south (not magnetic south). However, variations to the east or west by up to 15° will normally decrease the total energy output of the array by no more than 5%. If the load pattern is consistently heavier in the morning or afternoon, and there is no battery storage, it may even be desirable to orient the array away from true south.

Tilt angle refers to the angle between horizontal and the surface of the array. Normally the tilt angle is kept within 15° of the latitude of the installation, i.e., for a site located at 50°N, the tilt angle will normally be within the range of 35° to 65°.

With the longer summer daylight hours, and the higher summer sun angles (which reduces atmospheric absorption of sunlight), photovoltaic systems in Canada normally have a high tilt angle (10-15° greater than the latitude) as this will give the most constant output on a year round basis. High tilt angles also have the advantage of minimizing snow and dirt buildup.

For many smaller fixed arrays, it is feasible to construct the array mounting structure so that manual adjustments of the tilt angle can be performed 2 or 4 times per year, thus maximizing solar energy collection year round.

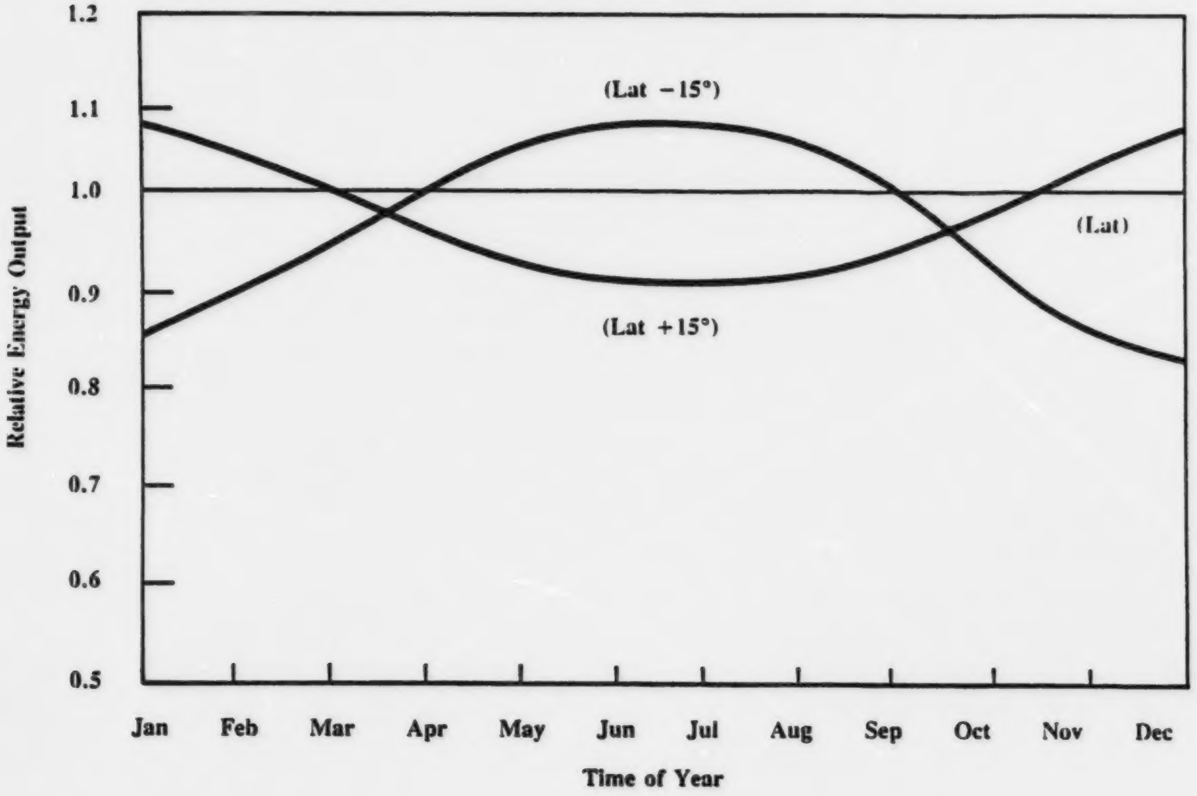


Figure 4.1: Effect of Array Tilt on Annual Energy Production

4.4 Shading

Shading of the array by nearby obstructions (trees, poles, buildings, etc.) can seriously affect the performance of a photovoltaic array. If one or more cells in a series string of modules is shaded, it not only fails to produce energy, but it blocks the power being generated by the other cells in the string. This has the effect of reducing the power output of the full array, and of creating a condition which could cause a permanent failure. The shaded cells become "reverse biased" and dissipate some of the energy generated by non-shaded cells. The shaded cells heat up, and could fail. This problem is more serious in high voltage arrays, as there is more power to dissipate in each string. There is also the possibility of self-shading, where one part of the array shades another part. This is more of a problem in large arrays made up of several sub-systems.

Proper siting and use of bypass and blocking diodes (see Sidebar) minimizes the power loss due to shading, and reduces the risk of permanent failure due to localized heating.

Sidebar: Bypass and Blocking Diodes

Bypass Diodes:

Bypass diodes are recommended in an array where modules are connected in series, that is, when the nominal array output voltage is greater than 12 V (when using standard 12 V modules). The purpose of a bypass diode is to prevent a poorly performing module (due to localized shading or a permanent fault) from unduly affecting the power output of the entire array. In a simple series string, a bypass diode connected in parallel with a shaded module can act as a low impedance path, diverting current from the other modules in series from passing through the shaded (or faulty) module. The sum effect of a bypass diode is to reduce the string voltage by that of one module (normally 12 V), while maintaining the string current and protecting the shaded module from heat damage during module malfunction.

Where groups of modules are connected in parallel, with the parallel groups then connected in series, one large bypass diode should be connected in parallel with the entire group. Bypass diodes on individual groups need not be used.

Bypass diodes should be rated at roughly twice the peak current of the module, or group of parallel modules, which it is bypassing.

Most modules can be ordered with bypass diodes already installed in the junction box of each one.

Blocking Diodes:

If the array output voltage were to be lower than some other voltage source in the photovoltaic system circuit, current would flow through the array in a reverse direction, thus dissipating energy rather than generating it. This situation arises every night in systems with battery storage. Blocking diodes are used in series with the array to prevent current from flowing in a reverse direction.

In the simplest configuration, a single blocking diode is wired in series with the whole array.

In an array consisting of more than one series string, blocking diodes are connected in series with each string. If the output voltage of one string falls with respect to the others due to localized shading or a fault, the blocking diode serves to isolate the affected string, preventing power generated in the remainder of the array from being dissipated in the affected string, and thereby maintaining the output voltage of the remaining strings at their normal operating level.

Where blocking diodes are included with each string, a blocking diode in series with the full array is not needed.

End of Sidebar

4.5 Series/Parallel Arrangement:

The number of modules used in an array connected in series is determined by dividing the nominal voltage of the load by the nominal module voltage. For example, if the array charges a 48 V battery bank, 4 standard 12V modules are used in series. The number of modules in parallel is determined by the required power. For example, five 10 peak watt modules in parallel are used to meet a load of 50 peak watts. Design procedures for array sizing for different types of systems are given in Section C.

There are two basic methods of obtaining the required series/parallel arrangement: several series strings can be connected in parallel or several parallel groups connected in series.

In an array incorporating series strings, a single shaded module will cause the individual bypass diode to activate and pass the current from the other series-connected modules. By removing one module from the active circuit, the output voltage of this string will fall proportionately. This, in turn, will cause the blocking diode to activate, effectively removing the entire string from the array, and reducing the power output of the array. The net output of the array will be reduced in proportion to the number of strings in the array.

In an array incorporating parallel groups, shading of one module will cause the bypass diode around the parallel group to activate, shunting the current from the other groups around the affected group, thus effectively taking the group out of production. The net result will be that the array output will be reduced in proportion to the normal contribution of the one group.

Because most loads require a minimum voltage (battery charging and most electronics), it is desirable to maintain the nominal output voltage of the array, and thus arrays using series strings are much more common. For loads which require a constant current, however, (such as an electric motor requiring a constant torque to drive a positive displacement pump), an array consisting of parallel groups in series may be preferable.

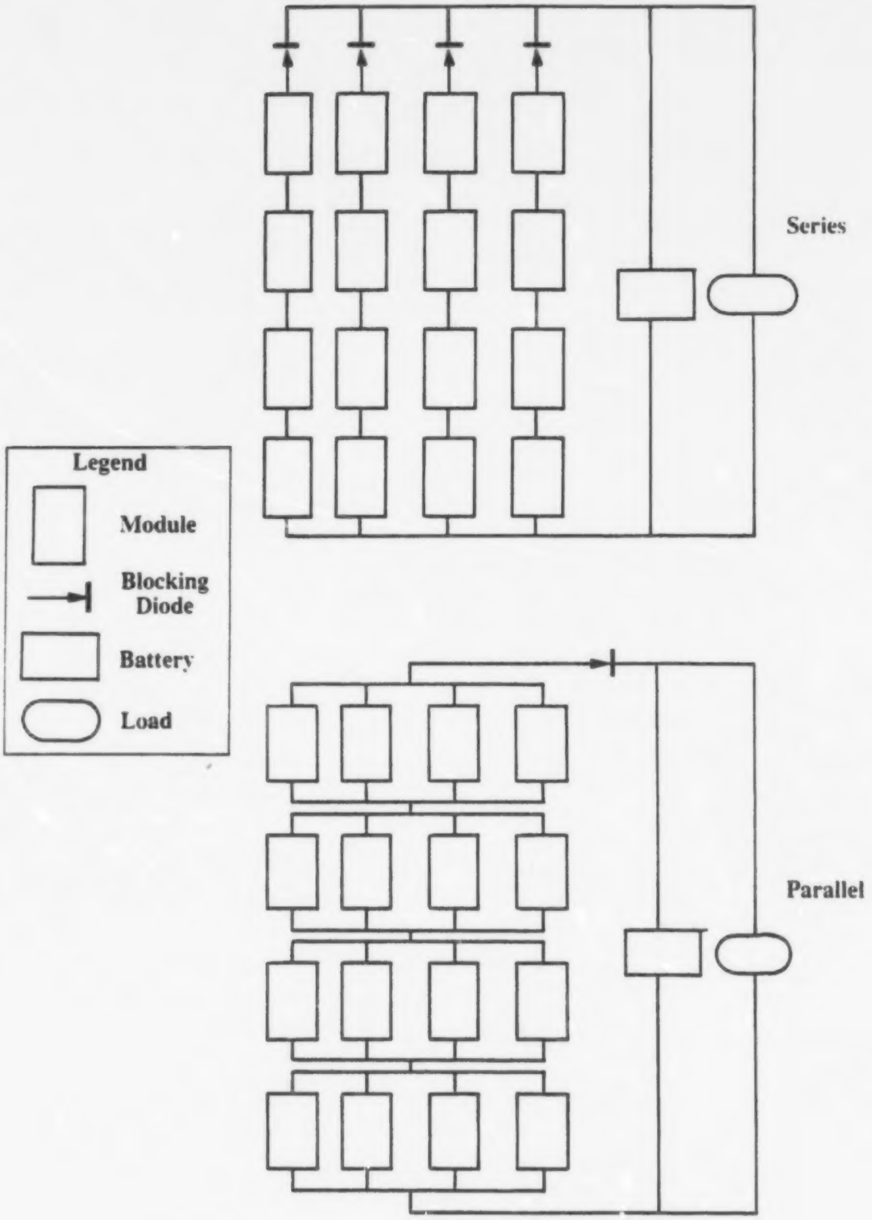

Series
Legend
Module
Blocking Diode
Battery
Load
Parallel

Figure 4.2: Series and Parallel Connection of Modules

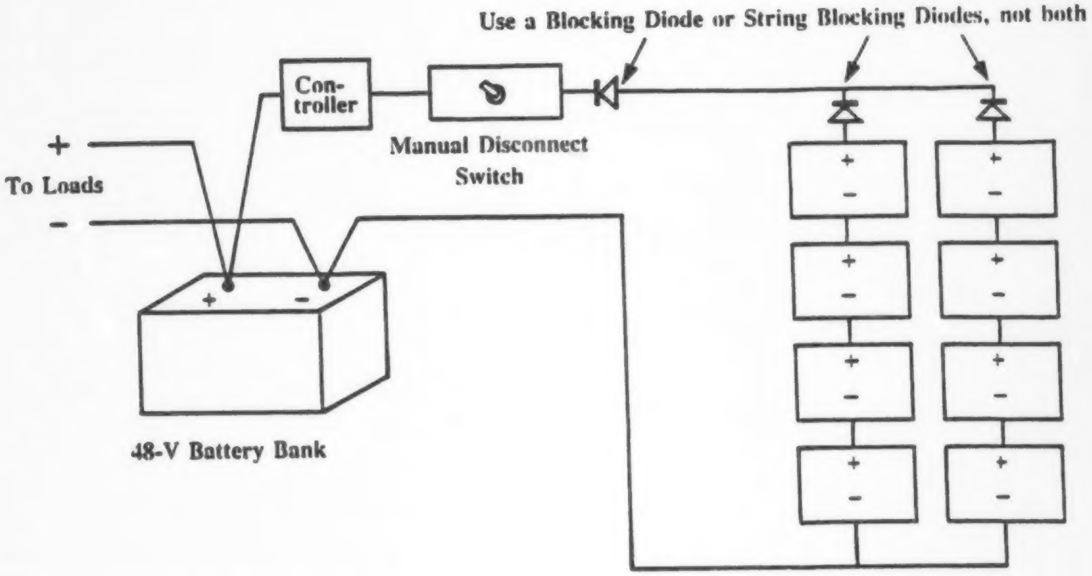

Use a Blocking Diode or String Blocking Diodes, not both
Con-troller
Manual Disconnect Switch
+
To Loads
-
+
-
48-V Battery Bank
+
-
+
-
+
-
+
-
+
-
+
-
+
-
+
-

Figure 4.3: Typical Blocking Diode Connection

4.6 Array Grounding

Two types of grounding are needed in all PV systems -- equipment grounding and system grounding.

Equipment Grounding: Grounding the equipment serves several purposes, all related to safety:

- Static charges built up on outer conductive surfaces of the array can be bled to ground before they reach hazardous levels;

- Leakage currents caused by faulty modules or wiring can be bled to ground and activate ground fault detectors to alert personnel of the problem;

- Grounding is the main defence against lightning.

For adequate protection, a resistance to ground of no more than 5 ohms is desirable. Dedicated electrodes can be installed for this purpose. See the Canadian Electrical Code for more on grounding.

System Grounding: For system grounding, one of the current carrying conductors is grounded at a single point.

Either the positive or negative side of the array may be grounded, or it may be grounded in the centre. Center grounding provides some advantages in terms of lowering the maximum voltage differential from ground, thus increasing safety for higher voltage arrays (e.g. a centre grounded 100 Vdc array would have a maximum of 50 volts above or below ground), and in providing two working voltages without the use of a voltage converter (e.g. 48 Vdc between the -ve and +ve array output cables, and 24 Vdc between ground and either arm of the array output). This latter feature can be useful where a variety of loads, with different operating voltages, are to be powered from the same array.

Ground fault interrupters should be included in the grounding circuitry. Such devices will protect equipment and personnel if faults within the array cause unacceptably large leakage currents to ground.

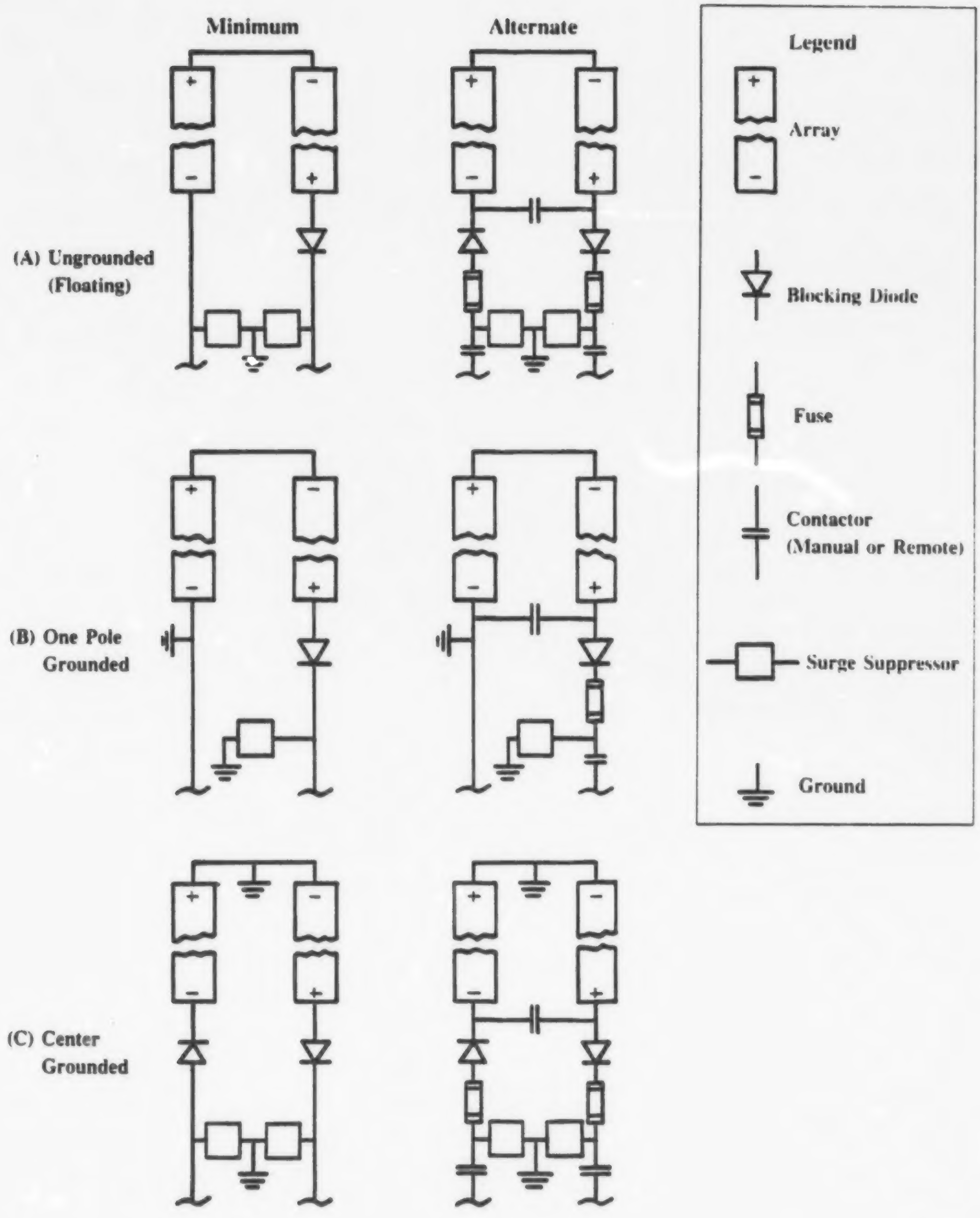

Minimum
Alternate
Legend
Array
Blocking Diode
Fuse
Contactor
(Manual or Remote)
Surge Suppressor
Ground
(A) Ungrounded
(Floating)
(B) One Pole
Grounded
(C) Center
Grounded
+
−

Figure 4.4: Possible System Grounding Configurations

4.7 Hazards and Protection

Lightning and Power Surges: There is little that can be done to protect a system from a direct lightning strike, but power surges caused by nearby strikes can be controlled. These would otherwise damage electrical equipment such as the control or load circuitry in a photovoltaic system. Good grounding can help dissipate much of the excess energy, and metal oxide varistors, or movistors, can be installed across the output of the array to clamp voltage surges and dissipate excess energy across a spark gap.

DC Disconnect: The other hazard to protect against, is simply that there is no suitable method of turning off the array during daylight hours for maintenance and service of the rest of the system. A dc disconnect should be provided to isolate the rest of the system from the array. For smaller arrays an opaque cover can be placed over the entire array. The most effective means of coping with this problem is simply to make everyone, particularly maintenance personnel aware of this potential hazard.

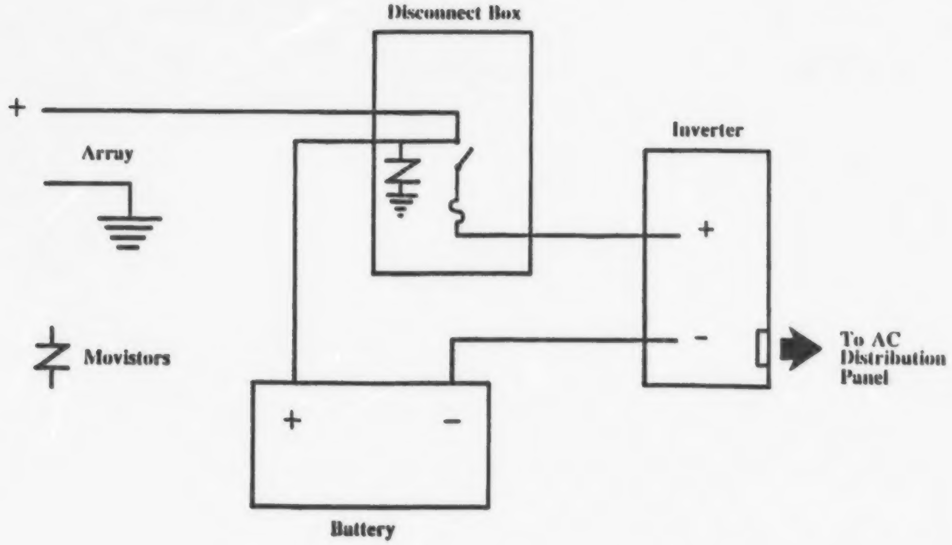


Figure 4.5: Use of Movistors to Provide Surge Protection

4.8 Wiring Methods

An array can be wired using one of three generic approaches. Module dimensions and available array space will determine which is used.

'Octopus' Wiring Methodology:

Individual cables run from the panel junction box to each module, and the boxes are then wired in series to provide the required voltage for a string. The panel fabrication and wiring can be done in the factory, with the wiring to the box and module plug-in remaining as the only electrical tasks to be handled in the field. This methodology usually is the least expensive, but the number of loose wires may pose a maintenance problem.

'Harness' Wiring Methodology:

From either side of the panel junction box, a single harness with a number of branch wires connect to the individual modules. Both single and dual harness concepts are possible, and only the termination of the panel junction box and the module plug-in are performed in the field. This is considered to be the most expensive option of the three types.

'Panel Daisy-Chain' Wiring Methodology:

This configuration involves direct interconnection of the module output cables (positive to negative) until a suitable output voltage is achieved. This concept requires lightning protection for the panel junction box, blocking diodes and a test point.

CHAPTER 5

ARRAY SUPPORT STRUCTURES

5.1 Support Structure Materials

For all photovoltaic systems, a durable support structure is required to mount the solar modules.

Systems for permanent applications need to be strongly constructed to resist extreme wind loads, whereas systems designed only for seasonal use may be mounted on a trailer or on a frame that is removed at the end of the season.

Most support structures for stand-alone systems are ground-mounted. While some are designed to track the sun in order to optimize output, the majority of support structures are fixed and arranged so that the array faces south at the required angle.

Many manufacturers of photovoltaic modules offer frames for the attachment of their own units. Arrangements for ground mounting of these frames must usually be made by the user, although advice can also be obtained from module suppliers. For larger systems or when the site requires special hardware, many designers prefer to build their own mounting hardware. A wide range of materials can be used to support photovoltaic arrays. (see Sidebar)

Sidebar: Materials Used in Array Support Structures

Aluminum: This is an easy material to work with, and is lightweight, strong and corrosion resistant. Holes can be drilled easily and the material is compatible with most module frames. However, it is not easy to weld and specially-built brackets are expensive.

Angle Iron: This material is readily available, easy to work with, and can be welded easily. Despite the ability of galvanizing to retard the process, it corrodes rapidly and corrosion in a coastal area may limit the life of the array mount.

Stainless Steel: This material will last for decades and often is a good investment for use in salt spray environments. However, it is expensive and difficult to work with.

Wood: This material usually is the least expensive and most readily-available option, and it is easy to work with. However, it must be pressure treated and is not recommended for use in damp or termite-prone climates. Battens or other clips are required to hold the modules in place.

End of Sidebar

5.2 Design Criteria

There are seven design criteria which apply to all types of array support structures:

Load Resistance: The structure must withstand the calculated structural loads, which means ensuring that the structure is capable of withstanding pressure of 1 m of snow and winds of 200 km/hr.

Orientation: The structure must provide a stable base, holding the array at the required orientation and tilt angle.

Clearance: Air must circulate freely behind the arrays for cooling. A space between the arrays and the support structure (or roof, in some installations) is required.

Grounding: The structure must be electrically grounded if conductive materials are used.

Aesthetics: The array should be supported in ways that are compatible with the application. This may involve making the array obvious to the eye in some cases and hiding the array in others.

Cost Effectiveness: The structure should be well engineered, and should be built and installed at the minimum cost that provides an adequate job.

Security: The system must withstand vandalism and unauthorized tampering.

Durability: It should last 20-30 years with minimal maintenance.

For ground-mounted arrays, the design should take into account the soil and climate conditions at the site. For example, conditions of bedrock or conditions of soils with frost heave would each require a special design.

For roof-mounted arrays, the frame must be designed to transmit the loads imposed on the array to the roof structure without placing undue stress on the structural components of the roof.

5.3 Estimating Structural Loads

Photovoltaic arrays are subject to similar natural forces which affect buildings, and experience gained from building design is useful in predicting approximate loads. Wind, snow, rainfall, seismic and dead loads must all be resisted by the structure. For most photovoltaic installations in Canada, the snow loads and wind loads are the most important.

The National Building Code (ref. "National Building Code of Canada 1980" issued by the Associate Committee on the National Building Code, National Research Council of Canada, Ottawa, and "The Supplement to the National Building Code of Canada 1980") provides formal guidelines on calculating expected loads due to snow and wind loads. Climatic information from 650 sites in Canada is provided. These calculations are not intended to be used for determining stresses on array structures but, in the absence of other information, they are a good starting point. In addition, the document entitled "NBSIR 81-2199, Wind, Earthquake, Snow and Hail Loads on Solar Collectors" (Cattaneo, 1981, published by the U.S. National Bureau of Standards) is also useful.

Sidebar: Snow and Wind Loads

For most areas in Canada, snow loads for a 30-year return period range from 1.5 to 4.0 kN/m^2, with occasional values as high as 8.0 kN/m^2 for mountain stations (a kilo-Newton (kN) is a measure of the force exerted). These loads may be reduced by a factor of 0.6 in an exposed location where snow can easily be blown off the array, provided that no significant projection exists to prevent snow from being blown off.

Wind loads for a 30-year return period are in the range of 0.2 to 0.7 kN/m^2 at the majority of sites in Canada, with values of up to 1.2 kN/m^2 at some arctic locations. These loads are based on hourly wind velocities and must be multiplied by a factor of 2.0 to allow for the effects of gusts. Because most installations have extended battery backup, the use of 30-year return period snow and wind data, together with a safety factor, is normally adequate.

The National Building Code Supplement also lists 100-year return period snow and wind pressures for all stations, and these may be useful if required. The chances of 30- and 100-year return period events being exceeded during the 20-year life of a PV installation are 49% and 18% respectively.

Snow loads are exerted downward, and wind loads have both lift and drag components. For wind loads, the lift and drag forces vary with the wind direction and the angle of inclination of the array. The use of the pressures from the National Building Code, together with the whole area (rather than the projected area perpendicular to the wind) of the PV array, enables a maximum estimate for the lift or drag forces to be determined. This will give an approximate number estimate for forces on which to base the required strength of the ground attachments for the array structure.

End of Sidebar

5.4 Ground-Mounted Support Structures

A wide variety of possible procedures exists for supporting small arrays.

The simplest is the pole mount in which modules are attached on each side of a single pole set into a foundation. They are used for small systems (4-6 modules) in heavily shaded areas or where there is little ground space.

Small systems of up to 12 panels may also be supported by using pairs of aluminum girders of about 5 cm section (usually supplied by the panel manufacturer) spaced to straddle the panels. The panels are bolted to the girders in groups of 3 to 5 panels. Adjustable rear legs enable the structure to be set at the required angle. The footpads, which usually are made of heavy-duty galvanized iron, are attached to the ground by various procedures. For a temporary or seasonal system in termite-free climates, the footpads may be bolted to a 2 cm thick plywood sheet which is laid flat on a cleared and levelled section of ground, and weighted down with concrete blocks that are heavy enough to resist the overturning moment from high winds.

For a permanent system, the footpads may be attached to concrete blocks fitted with anchor bolts or steel support struts that are buried in the ground. The concrete blocks are either poured directly into an excavated trench or prepared in advance and partially buried at the site in shallow holes in the ground.

For installations larger than 12 modules, a special frame can be used. One such frame is usually 3 or 4 m high, to hold modules in twos or threes, one above the other. The frame includes steel or aluminum channels, into which the modules are attached. The channel is attached to wooden beams that are assembled in a similar way to a roof truss.

Figure 5.1 shows a simple ground mount with wooden carrier beam and steel ground support struts. The steel support struts (galvanized steel pipe may also be used) may be let into the ground by using a 20 cm diameter disk auger anchor, of the sort commonly used to secure mobile homes. For many Canadian locations, the foundations for permanent installations must be buried deeply to overcome frost heave problems. Where a deep frost heave problem exists, galvanized steel pipes can be sunk into the ground to a distance of at least 1 m with disk auger anchors. Other types of ground mounting systems are shown in Figures 5.2 and 5.3. All ground mounted arrays should be high enough to keep the array above normal snow levels and drifts.

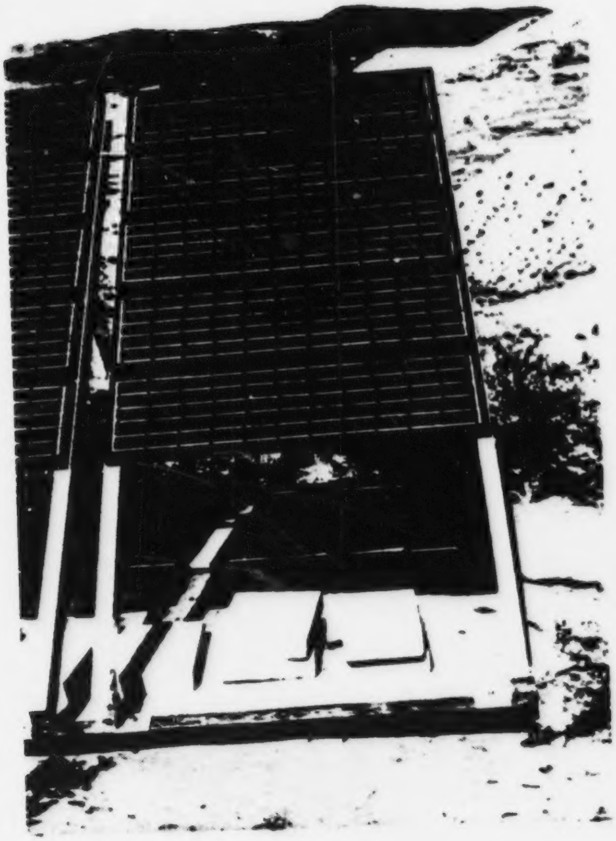
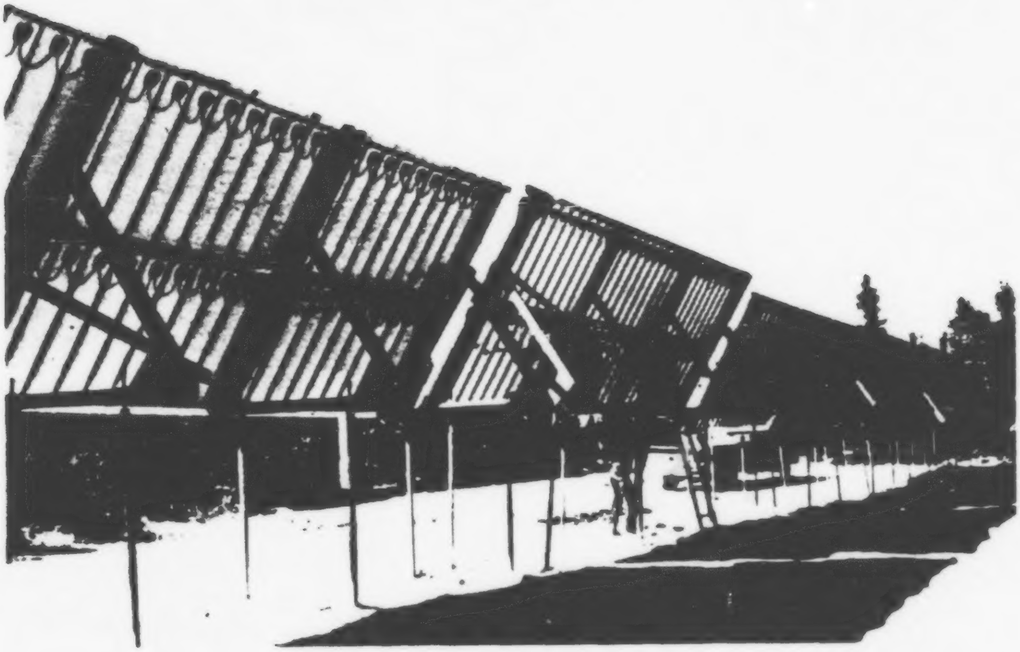
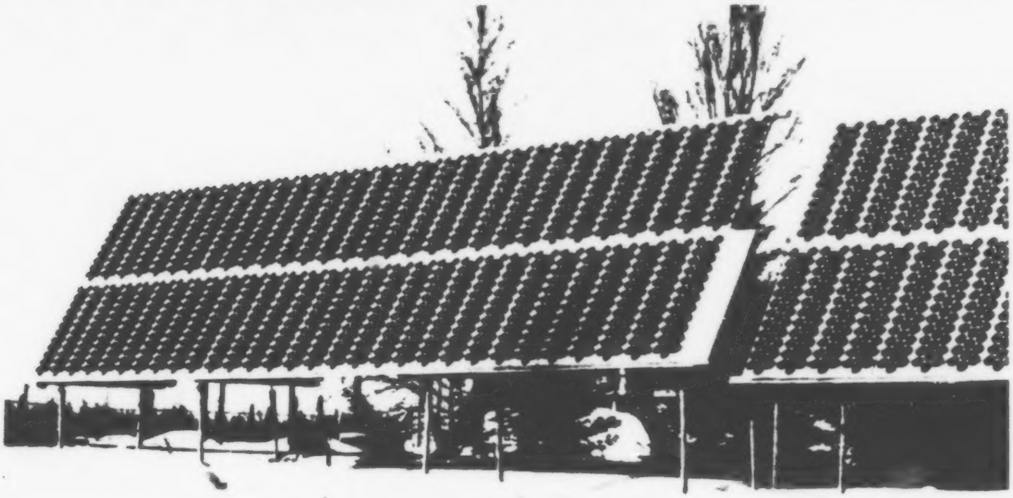


Figure 5.1 Temporary Ground Mount for Small Systems



Rear View of Ground Mounting System at Big Trout Lake



Ground Mounting of a Large Array at Big Trout Lake, Ontario

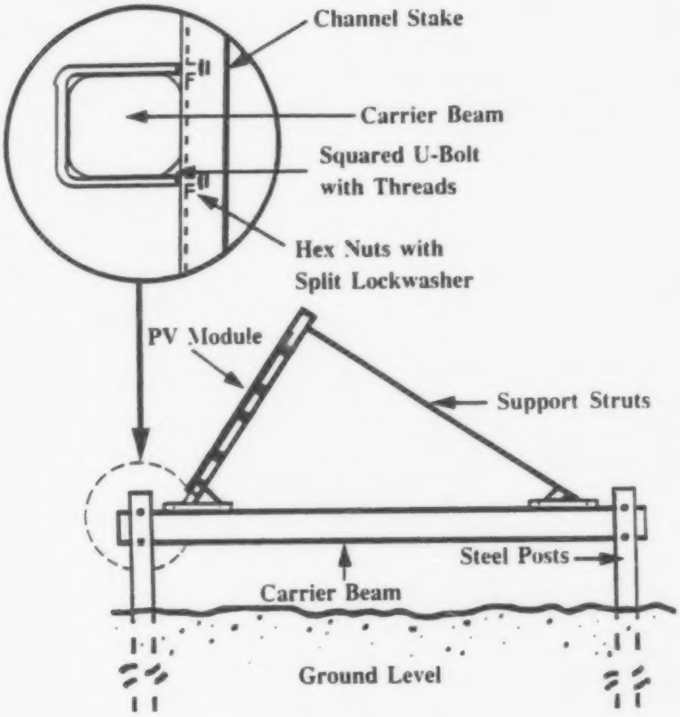

Channel Stake
Carrier Beam
Squared U-Bolt with Threads
Hex Nuts with Split Lockwasher
PV Module
Support Struts
Steel Posts
Carrier Beam
Ground Level

Figure 5.2 Simple Ground Mount

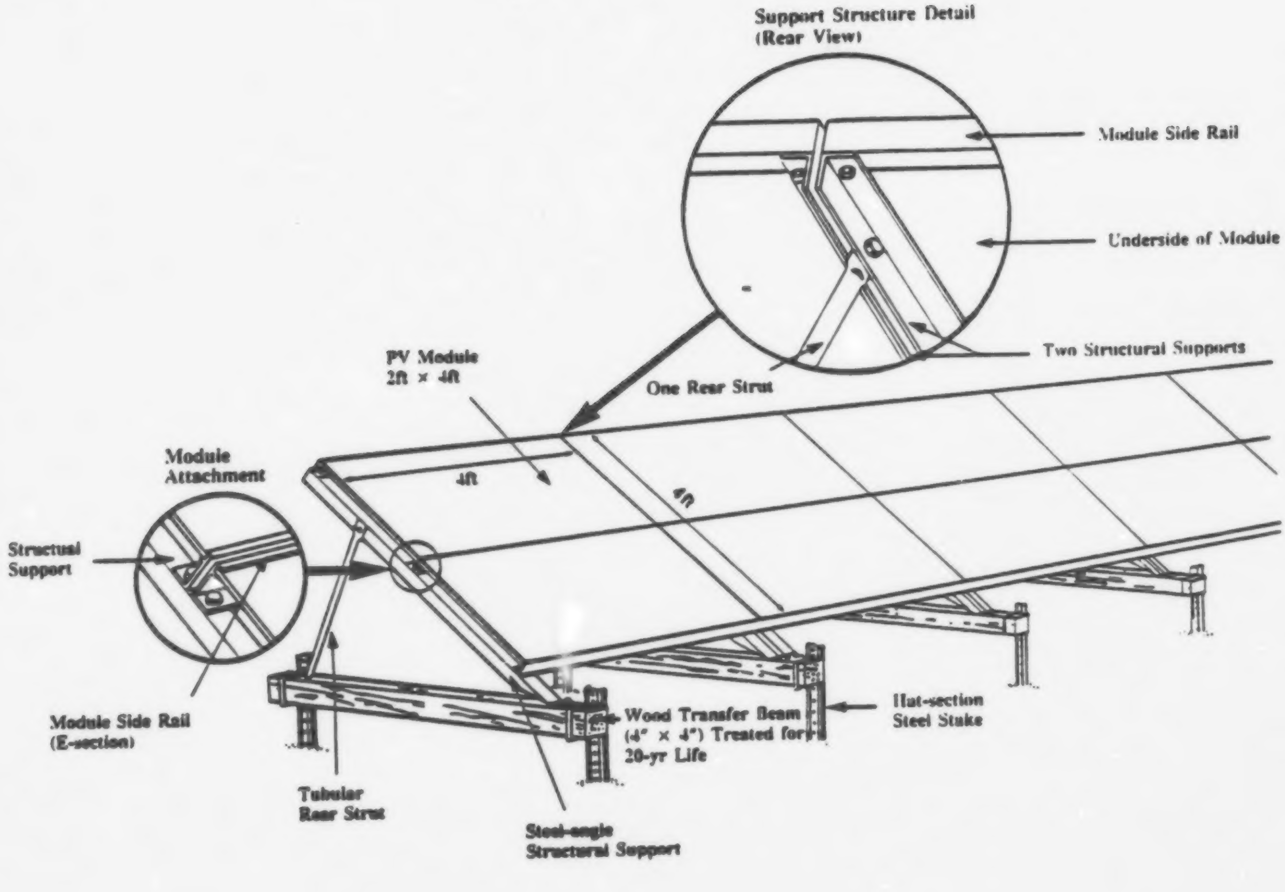

Support Structure Detail
(Rear View)
Module Side Rail
Underside of Module
Two Structural Supports
One Rear Strut
PV Module
2ft × 4ft
Module
Attachment
4ft
4ft
Structural
Support
Module Side Rail
(E-section)
Wood Transfer Beam
(4" × 4") Treated for
20-yr Life
Hat-section
Steel Stake
Tubular
Rear Strut
Steel-angle
Structural Support

Figure 5.3 Array - Field and Mounting Block

5.5 Roof-Mounted Support Structures

Roof mounting of arrays has some advantages over ground mounting:

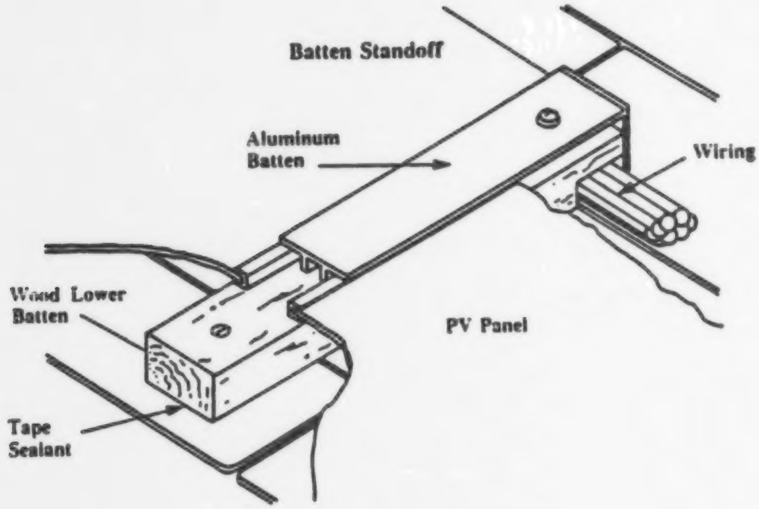
- less chance of shading
- less chance of vandalism
- closer to the load
- does not use up ground space

A roof-mounted array must be able to adapt to existing roof conditions, while retaining a low profile and paralleling the slope of the roof. Many components of the building (eg. chimneys, vent stacks, attic vents, dormers, etc.) can shade an array and allowance must be made for this in placement of the modules. Figures 5.4 and 5.5 shows typical roof mounting systems.

It is vital to achieve a firm and secure attachment of the array mounting brackets to the roof, and attaching the brackets to the rafters will give the best foundation. However, this can be difficult when the rafter spacing is not compatible with the size of the modules.

If access can be gained to the underside of the roof, wooden blocks can be inserted between the rafters and the attachment made to the blocks. If this is not possible, the array can be attached to the plywood sheathing, but only if the total roof load, as required in the Building Code, is not exceeded.

In all roof-mounted arrays, a clear air flow must be allowed under the array. The array will operate at cooler temperatures and produce more energy if the modules are at least 7 cm off the roof. Direct mounting of modules to the roof of a building is not recommended due to the increased difficulty of testing and replacement as well as the decreased performance as a result of higher operating temperatures.



Batten Standoff
Aluminum Batten
Wiring
Wood Lower Batten
PV Panel
Tape Sealant

Figure 5.4 Roof Mounting Using Batten Stand-off

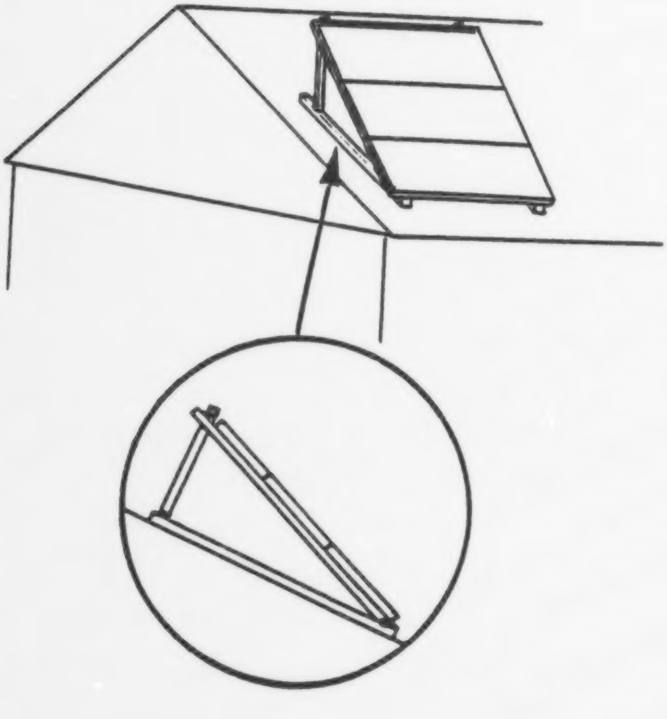


Figure 5.5 Roof Mounting Using Mounting Legs

5.6 Tracking Structures

Due to the daily path of the sun across the sky and the seasonal variation in its altitude, some photovoltaic installations may benefit from a 'sun tracker' which can ensure optimal orientation of the array towards the sun at all times.

A passive solar array mount has no motor, controls or gears, and relies on the changing phase of a refrigerant (usually freon) from liquid to gas within a sealed frame member to track the sun. Sunlight evaporates the refrigerant and the frame assembly moves by gravity or is piston driven. Passive trackers are less reliable in winter since there is less heat available to drive the freon piston, and joints may stiffen up due to the cold. Trackers which use small integrated photovoltaic modules to drive the tracking device (differential controller and positioning motor) are also commercially available. Tracking mounts can be single- or dual-axis trackers. The former follows the sun's path from east to west but not its change in height above the horizon. The tilt of single axis trackers can be seasonally adjusted to optimize altitude angle. For mid-latitude locations, however, changing the tilt angle every three months will increase energy production by less than 5%, yet incur a cost penalty due to the additional labour and added complexity of the array mount.

Tracking mounts require firm foundations because of their weight and wind loading characteristics. An outside pipe of 10 to 15 cm diameter is commonly set in reinforced concrete footings to ensure long-term safe operation. The tracker stem is then placed over the pipe. Sufficient height above ground level is required in order to allow the tracking unit to move without being obstructed by snow or debris.

Most trackers used for small stand-alone systems are pole-mounted and support 4 to 12 modules. Normally, the mounting hardware is supplied by the manufacturer. The amount and type of foundation for the tracker depends on the size of the array being supported, but reinforced concrete with anchor bolts is recommended. The design of the foundation and frame should be able to withstand the worst case wind expected in the area.

Since the sun describes a very small arc across the sky in winter, the value of tracking arrays is greatly reduced. Larger fixed arrays are used in preference to tracking arrays in Canada if a year-round load is to be met.

Since most of the trackers are manufactured in the United States, system designers must ensure that units for use in Canada are able to adjust their angle to more than the 45° maximum provided on many models. Special finishes are available and some units are available in stainless steel with plastic bearings for use in corrosive climates.

Many trackers are designed to automatically move to a "storage" position in high winds above about 50 kph. This can reduce the amount of energy collected at windy sites.

CHAPTER 6

ENERGY STORAGE IN BATTERIES

Batteries provide three important functions in a photovoltaic system:

- Autonomy - the system can meet the load at all times even at night or overcast periods.
- Surge Current - the system can supply short-term surges in current higher than the array output current to start motors and other equipment.
- Levelling Voltage - the system can provide a constant voltage by eliminating wide swings in array voltage.

The two most common battery types used in photovoltaic systems are lead-acid and nickel calcium -- see Sidebar.

Sidebar - Lead Acid Batteries

A lead-acid battery stores electric charge in the form of chemical energy. When a battery is connected to a load, a chemical reaction occurs between the lead, lead oxide, and the electrolyte of sulphuric acid. This, in turn, results in a flow of electrons through the battery and into the load.

In a lead-acid battery, the powdered lead and lead oxide pastes are dried onto an electrode grid that holds the material in place while acting as a collection grid for the electrons that flow in the battery.

The grids are made of pure metallic lead, or an alloy of lead and other elements. Pure lead grids lack strength and are frequently restricted to stationary batteries. They have very low rates of self-discharge, but cannot be discharged too deeply nor recharged too fast. They are suitable for use in photovoltaic systems if these limitations are taken into account.

Some battery manufacturers use antimony to add strength to the lead. Lead-antimony grid batteries are used in automobiles because the grid can withstand the rolling vibrations, and they can accept a fast rate of charge and deliver fast discharge rates. The latest development for electric vehicles and other heavy-duty applications can be repeatedly deep-discharged to 50-80% of capacity, but will bubble early during recharge and lose water near a full state-of-charge. As a result, these batteries must have their water level restored periodically, and are suitable for PV systems if limited maintenance is available.

Calcium can also add strength to a lead grid and reduce the gassing and loss of water experienced by lead-antimony types. This type of grid alloy is used in maintenance-free batteries because sufficient liquid is added during manufacture to handle the loss over the five-year life of a battery. However, the life of the battery will be shortened if it is deeply discharged repeatedly, and a maximum of 25% depth-of-discharge is recommended. This battery is still an economical choice and the maintenance-free quality makes it attractive for remote PV applications.

Lead-acid battery cells commonly have a nominal voltage of 2.0 volts. A battery is usually constructed with 3, 6 or 12 cells in series, providing nominal voltage of 6, 12 or 24 volts. The actual operating voltage range will be 1.75 to 2.45 volts per cell depending on specific gravity and grid composition.

New battery technology is being introduced which uses sealed cases, and immobilized gel electrolytes. This will make transportation and handling of batteries safer and easier.

End of Sidebar

Sidebar - Nickel Cadmium Batteries

NiCd cells are designed for applications which require robust energy storage with long operating lifetimes and minimal maintenance. The active material on the positive electrode plate is nickel hydroxide which, during discharge, accepts electrons from the external circuit, which moves it into a lower valence state. The negative plate is composed of cadmium, and the electrolyte is a 20-35% solution of potassium hydroxide in water. Cell voltage is commonly 1.2 volts.

The electrodes in these cells undergo changes in oxidation with no change in physical state. Because the active materials are insoluble in the alkaline electrolyte, they remain in a solid state and no active material is lost in the discharge process. Unlike lead-acid cells, the electrolyte in a NiCd battery acts only as a medium to transport ions, and the specific gravity of the electrolyte is maintained regardless of state-of-charge. Because the oxygen generated during reaction recombines with hydrogen to form water, hydrogen is not vented by these batteries and they can be overcharged regularly without excessive gassing and increase in internal pressure.

NiCd batteries have a number of advantages: a 20-year life; minimal maintenance; overcharge withstand capability; over-discharge and reversal withstand capability (without suffering permanent damage); relatively flat operating voltage as a function of state of charge; good performance at high temperature; good low temperature capacity; and they may be left in a charged or discharged state without damage.

Nickel-cadmium batteries are available in sealed or vented units, and are available with sintered plate or pocket plate construction. A sintered plate involves impregnating the active material into nickel support plates to lower internal resistance and sensitivity to variable temperature operation. The pocket plate design places active material in perforated pockets and features more rugged cells with long life and the ability to withstand extended periods at partial states of charge without sustaining damage. They also require less maintenance.

Sintered-plate nickel-cadmium cells can suffer from a 'memory effect' during discharge which can affect the discharge voltage. If a sintered plate NiCd cell is repeatedly discharged to a particular depth, subsequent discharge beyond that level will result in a voltage reduction from the normal discharge characteristic. The degree of reduction depends on the number of repetitive cycles, but the temporary effect can be erased by subjecting the cell to a single complete discharge/charge cycle. Sintered plate cells are used only in small photovoltaic applications.

A vented pocket plate cell can have a capacity of between 5 and 1,300 Ah, while a commercially available sealed sintered plate cell can range from 0.1 to 23 Ah. Increased capacity can be achieved if the cut-off voltage is lowered, with the most significant increase occurring in the vented, medium rate, pocket plate cell.

Although generally more expensive than lead acid batteries, the ability of NiCd batteries to withstand "abuse" (e.g. overcharging and over-discharging) sometimes allows the use of simpler and less costly charge control equipment.

End of Sidebar

6.1 Battery Characteristics

Battery Capacity:

The capacity of a battery is a measure of the amount of charge that can be stored. The capacity is normally given in ampere-hours at the nominal voltage of the battery under standards conditions of 25°C and charge rate (8,24 or 100 hrs.) If more storage capacity is required to meet a specific application, batteries are connected in parallel. If greater voltage is required, the batteries are connected in series.

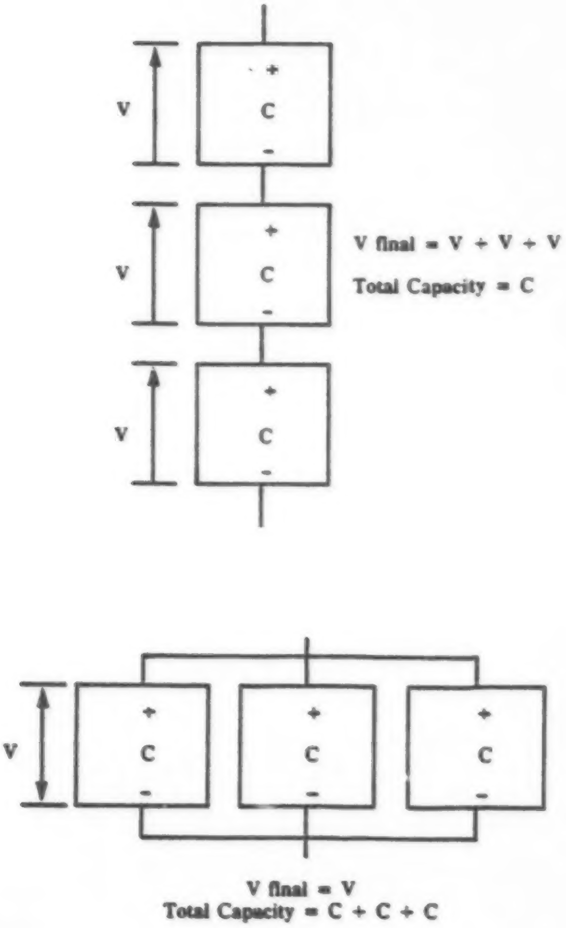

V
+
C
-
V
+
C
-
V
+
C
-
V final = V + V + V
Total Capacity = C
V
+
C
-
+
C
-
+
C
-
V final = V
Total Capacity = C + C + C

Figure 6.1: Combining Batteries

Discharge Rate:

The discharge rate of a battery is usually expressed in amperes or in discharge time. The discharge time is the time it would take to discharge the battery completely at the discharge current.

> Rate (amps) = Capacity (Ampere - hours)/Discharge Time (hours)
>
> For example, if a battery is discharging at a rate that would fully discharge it in 50 hours, it is said to discharge at a "C/50" or "50 hour" rate.

A C/10 charge rate is the fastest that can be used without "gassing". A C/20 rate is the most common while a C/30 to C/100 is used for "float" charge.

State of Charge/Depth of Discharge:

The state of charge is the fraction or % of full charge (100% at full charge, 0% when fully discharged).

The depth of discharge (DOD) is the degree (fraction or %) to which the battery is discharged before it is recharged in a given application. DOD usually varies between 20% (shallow discharge) and 85% (deep discharge) depending on type and application (see below).

Battery Voltage:

Actual battery voltage depends on the type of battery, specific gravity, and varies with the state of charge, the rate of discharge or charge, and temperature. It is slightly higher when charging than when discharging. Figures 6.2 and 6.3 show these effects.

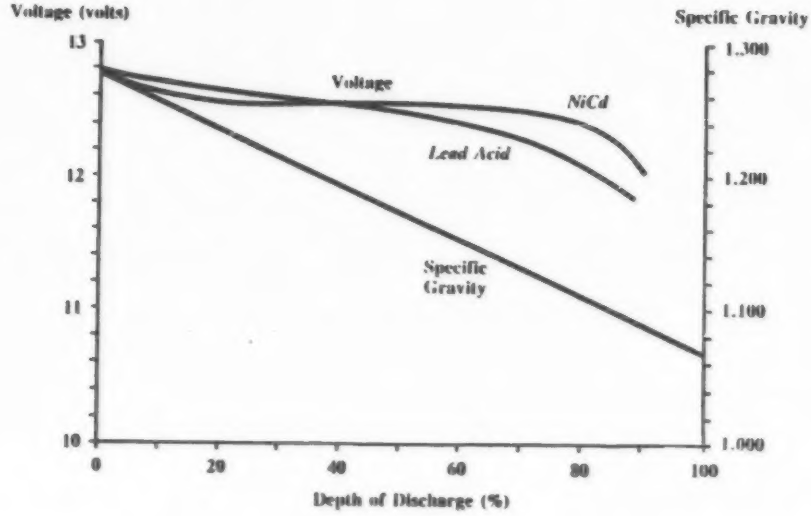


Figure 6.2: How State of Charge Affects Battery Voltage

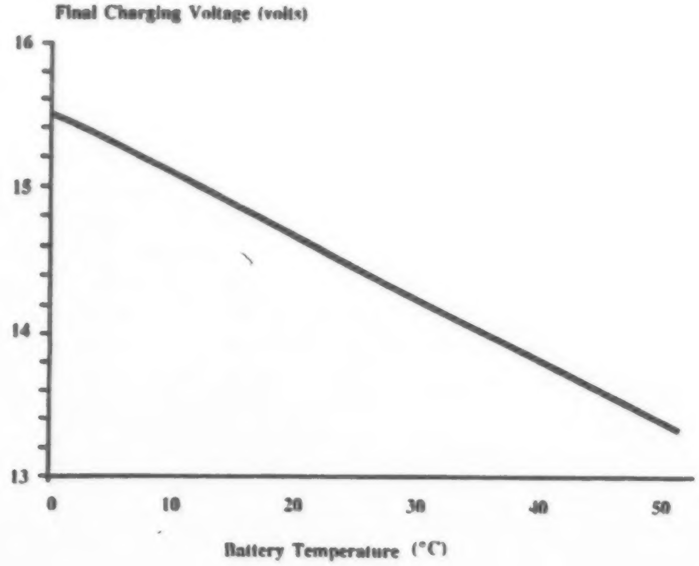


Figure 6.3: How Temperature Affects Battery Voltage

Usable Capacity:

The usable capacity of the battery is the percent of nominal capacity that can actually be used in a given application. It depends on the discharge rate and temperature of the battery:

- the higher the discharge rate, the lower the usable capacity of the battery;
- the lower the temperature, the lower the usable capacity of the battery.

These relationships are very important when sizing a battery for a photovoltaic system. Battery capacity is usually specified at the 100 hour (C/100) discharge rate and 25 C. If a battery operates with a 48 hour discharge rate at temperatures down to -20 C, only about 70% of normal or rated battery capacity would be usable. Figure 6.4 shows the relationship between usable capacity discharge rate and temperature.

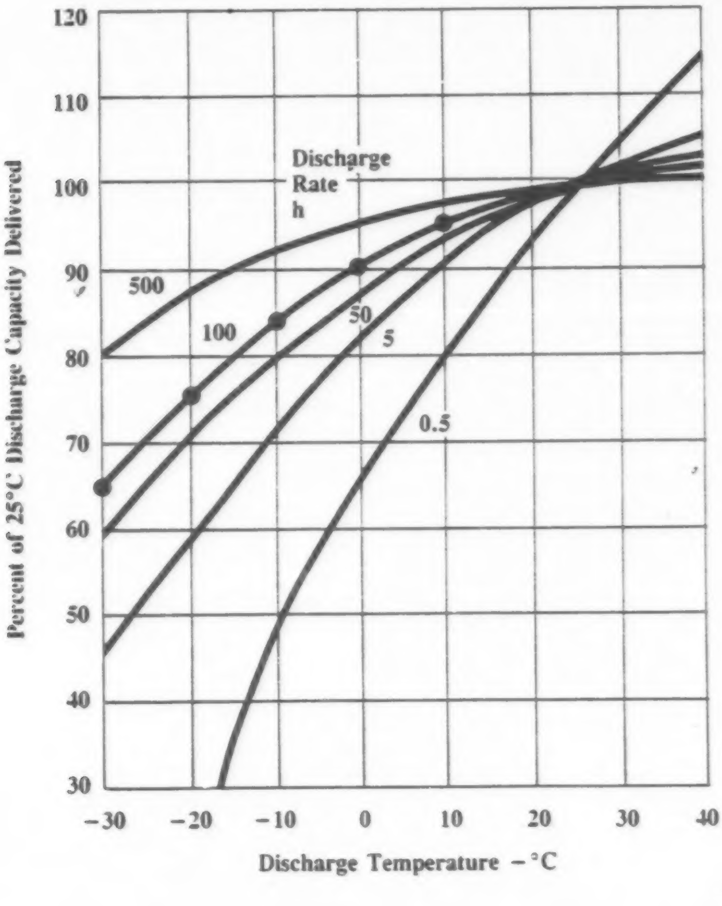


Figure 6.4: Effect of Discharge Rate and Temperature on 25^{0}C Capacity

Battery Life:

The most significant parameters affecting the life of a battery are depth of discharge and operating temperature.

If a battery is deeply discharged in each discharge/charge cycle, battery life, particularly in lead-calcium batteries is reduced. The deep discharge increases self discharge and reduces charge acceptance, thereby degrading cell performance. It will also increase the rate of decomposition of electrode separator material, causing internal short circuit. However, this latter effect is less severe for pocket plate NiCad battery cells than for lead-acid batteries with alloyed grids. The temperature effect on the life of sealed, sintered plate NiCad battery cells is primarily dependent on cell design and separator properties.

Cycle life can range from 200 to 10,000 cycles, although it is reduced by continuous overcharging, increased operating temperatures, or by high discharge rates and repeated deep cycling. Lifetimes of 7-15 years are expected from quality batteries in well designed applications.

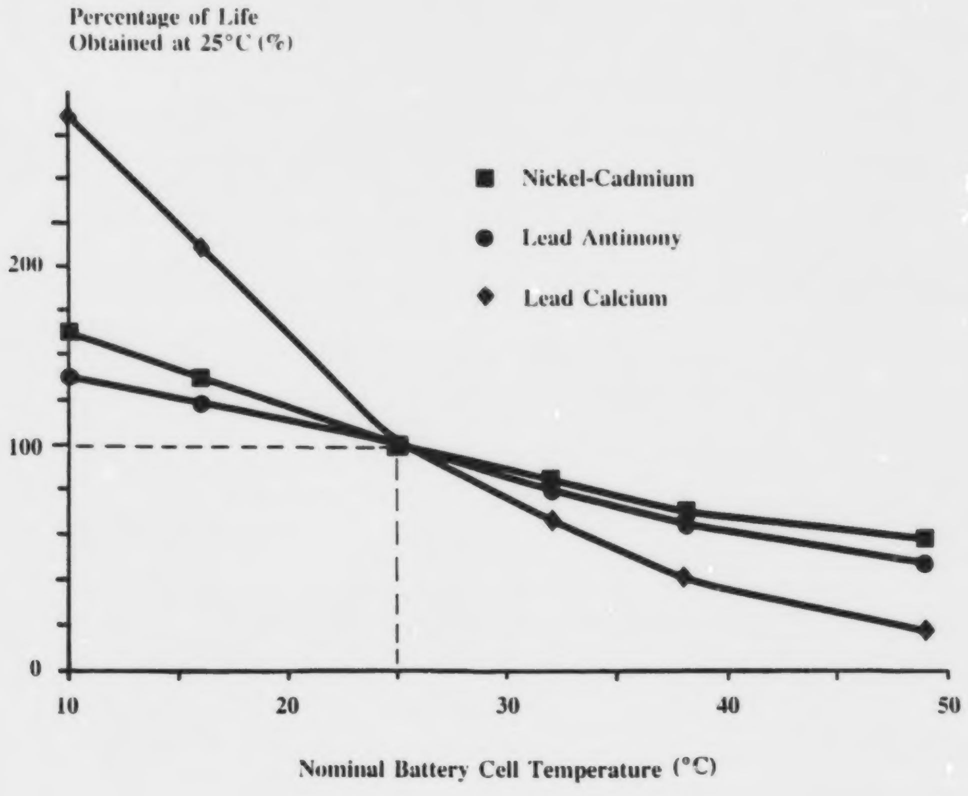


Figure 6.5: Effect of Temperature on Battery Life

6.2 Batteries for Photovoltaic Systems

Photovoltaic systems generally require a battery that can be charged during the day and discharged at night, with the ability of being able to withstand this cycling for many years with minimum performance degradation. The battery must, however, also be able to meet the design load during days of little or no sunshine. Two design parameters are important:

Days of Autonomy (DOA): The number of days which the battery can supply power to the load without being recharged or suffering damage.

Shallow or Deep Cycle Operation: Whether the required autonomy is met by a large battery capacity and a shallow depth of discharge (shallow cycle), or by a smaller battery capacity and a deep depth of discharge (deep cycle).

These parameters are related as follows:

$$C = L \ast DOA/DOD_c$$

where L = daily load in ampere hours and
DOD_c = depth of discharge in each cycle
C = Battery capacity in ampere hours

Shallow cycle systems are sized to use 15-25% of the battery bank capacity each night (for example, if the night load is 100 Ah, the storage bank would need to be 400 to 670 Ah in size). By designing for shallow cycle discharge, battery life is extended, lead-calcium batteries can be used, and a built-in reserve is available to accommodate a stretch of poor weather. Remote Canadian telecommunication systems for example are often designed with 20 to 30 days of system autonomy.

In a deep cycling system, the battery bank is sized so that 50-80% of capacity is used each night. Batteries with antimony in the grids can withstand this treatment for many years. Almost all the capacity is used, so fewer batteries need to be purchased, but there is little reserve in the batteries to handle the load during a long stretch of bad weather.

The actual size of battery required for a photovoltaic system also depends on the rate of discharge in each cycle and the (lowest) operating temperature because, as illustrated in Figure 6.4, the usable capacity is greatly reduced at high discharge rates and low temperatures.

The procedure for sizing batteries for specific photovoltaic applications is given in Chapter 10.

6.3 Electrolyte Stratification and Freezing

If the battery operates for long periods of time at a constant rate of charge, the electrolyte can stratify. It can be re-mixed by applying a high rate equalization charge.

If the battery is on a deep discharge cycle, there is a danger of electrolyte freezing at low states of charge when the electrolyte is mostly water and has a higher freezing point.

Select a battery whose electrolyte can withstand the ambient temperature conditions without freezing or provide a means to protect the battery such as burying below the frost line or an insulated box.

Table 6.1 shows the specific gravity and freezing point of an electrolyte in typical battery designed for temperate or cold conditions.

For extremely cold conditions, electrolytes with a specific gravity of 1.29 to 1.30 are used to prevent freezing during the discharge state.

Where possible, batteries are kept in insulated and/or buried enclosures to reduce heat losses. The Canadian Electrical Code suggests that batteries be kept above -7°C if at all possible.

TABLE 6.1

ELECTROLYTE SPECIFIC GRAVITY AND FREEZING POINT

State of Charge	Specific Gravity	Freezing Point (°C)
Fully charged	1.265	-60
75%	1.225	-40
50%	1.190	-23
25%	1.155	-16
Discharged	1.120	-10

6.4 Battery Safety

Liquid electrolytes produce explosive hydrogen and oxygen gas when charging. Batteries should be placed in a well ventilated area and away from other electrical components that could produce a spark. The ventilation rate required will depend on the size of the battery and its charging rate.

Batteries connected in series can provide a shock hazard. Insulated tools should always be used and DC isolation switches used when working on other parts of the system.

See Chapter 14 for more details on ventilation rates and electrical safety measures.

Batteries which have reached the end of their useful life must be disposed of safely and cleanly to prevent environmental problems.

CHAPTER 7

POWER CONDITIONING

Power conditioning hardware may be defined as any circuitry which modifies the power coming from the array to make it more compatible with the current and voltage requirements of the load. In practice, most photovoltaic power conditioners include at least some control functions, such as a low battery voltage load disconnect. Power conditioners range from simple devices which cut off the array power if it exceeds preset limits to devices which can maintain the array operating point at optimal, while producing ac power and dc power at several voltages.

7.1 Battery Charge Regulators

Battery charge regulators are the simplest and most common type of power conditioning hardware found in photovoltaic systems. Their primary function is to cut off charging current from the array to the battery when the batteries become fully charged. This is normally done by cutting off power when the battery voltage reaches the end of charge voltage (typically about 14.5 V for a nominal 12 V battery), although other types of battery state-of-charge detection, such as integrating the net charge into and out of the battery, are used. Other functions of a regulator may include a low voltage load disconnect, temperature compensation (for the end of charge and load cutoff voltages), battery equalization charge capability, etc. Some regulators are capable of being wired in parallel to increase their current handling capability. This is an important feature which increases redundancy and therefore reliability.

Single stage controllers connect or disconnect the array current. Two stage controllers have two "on" modes. The normal mode or first stage, allows the flow of full array current, while the second stage (trickle charge mode) allows the voltage to increase (to about 17-18 V on a twelve volt system). This type of charging is beneficial to most batteries, extending their life. See Sidebar for other features and options.

Sidebar: Features and Options in Battery Charge Regulators

. Shunt or series type. When a fully charged battery is sensed, a shunt regulator diverts current from the array directly to ground (or negative terminal on ungrounded systems) via a resistive load: a series regulator open circuits to stop any current flowing from the array.

. Capacity. This is normally the upper current limit (most regulators are for a fixed nominal voltage)

. Built in Blocking Diode. See Chapter 4.

. Temperature compensation. Usually tailored for a specific battery type (e.g. lead-acid) over a specified temperature range.

. Trickle or equalization charge capability.

. Current and voltage meters

. Lightning surge protection

. Reverse polarity protection. This protects against damage from inadvertent wrong connections.

. Load controls. This feature is used for turning certain loads on or off when the system voltage is below or above certain limits, i.e., for starting a generator, signalling an alarm when voltage is low, or turning on a resistance heater or pump when voltage is too high.

End of Sidebar

7.2 dc-dc Converters

Dc-dc converters are solid state electronic devices which change the input voltage and current levels to different output levels. Typically in a photovoltaic system a converter would lower the incoming voltage level (which varies with insolation and temperature), to a more constant level specified for the load. Dc-dc converters tend to be required where loads are sensitive to the supply voltage. Converters may have more than one output voltage (e.g. 48 and 12 Vdc), which is advantageous for some mixed loads. Because dc-dc converters operate at a high frequency (up to 20 kHz), ac ripple is introduced into the output waveform. Depending upon the level of this ripple, it may cause inefficiencies and additional heating of motors, failure to operate, or permanent damage to electronic loads.

Dc-dc converters may also be used to directly match the output characteristics of an array to a specific load, where batteries are not included in the system. A positive displacement water pump would be an example of where a converter would help.

Dc-dc converters are not common because loads in most stand-alone systems are designed to operate from a single voltage, that of the battery, and the battery also serves to "condition" and stabilize the voltage seen by the load.

7.3 Inverters

Inverters are required in systems which supply power to ac loads. Inverters convert the dc output of the array and/or battery to standard ac power similar to that supplied by utilities. Inverters which supply power of the same quality as utilities (in terms of frequency stability, voltage level, current and voltage wave shapes) are available, but, depending upon the requirements of the load, inverters which supply lower quality power may be more economical to use in autonomous systems such as stand-alone photovoltaic power systems.

In a system with battery storage, the inverter is normally wired so as to draw directly from the batteries or the battery charger. The battery charging function may also be integrated within the inverter.

As with other types of power conditioners, many or all system control functions may be integrated into the inverter.

Ideally an inverter for a stand-alone photovoltaic system should have the following features:

- Surge Capacity - Many inductive loads (motors) require a surge of current for a few seconds to get started, and then operate at a lower steady-state current level. An application that has many loads may have more than one operating at the same time for a few minutes. An inverter should be able to operate continuously at an expected "average" load level. However, it should be able to operate for several minutes above this level, and withstand surges over three times this base level.

- Voltage Regulation - The output voltage level should be well regulated so, as the input battery voltage drops (as the battery state-of-charge goes down), the output AC voltage level remains steady, preferable within 5%.

- Harmonic Distortion - The amount of unwanted harmonics in the output waveform should be chosen to minimize harmful heating effects in motors.

- Efficiency - The inverter should consume very little power itself to keep the overall efficiency of the power system high. It should operate at a high efficiency (>90%) over a wide range of loads, and should not use much power when it is on stand-by (when no loads are operating).

- Serviceability - The inverter should be easily serviced in the field, or should have modular electronics so that change-outs of malfunctioning circuits is easy.

- Self-Commutation - In stand-alone systems, the inverter must operate independently of a grid source of AC power.

Stand-alone inverters can be classified into three types on the basis of the type of AC waveform output they produce - square wave, sine-wave, and modified sine-wave:

Square-wave inverters are inexpensive and simply switch the DC input into a step-function or 'square' AC output. There usually is little output voltage control, minimal ability to surge, and a high amount of harmonic distortion that can cause heating in motors. This type of inverter is appropriate for small resistive heating loads or lights (where DC equipment cannot be used), and is not used if prolonged motor operation is anticipated.

Modified sine-wave inverters use transistors or silicon-controlled rectifiers to handle the switching, they can handle large surges (up to 400%), and have much less harmonic distortion in their output so they can operate motors very well.

Sine-wave inverters extensively filter the output power from the transformers to remove most unwanted harmonics (<5% distortion). They tend not to have the surge capability or efficiency of modified sine-wave types, but are appropriate where the load requires a very high-quality wave form, such as for delicate electronic switching equipment.

By incorporating a properly-chosen inverter into a PV power system, a wide variety of easily-available, inexpensive and convenient applications can be operated.

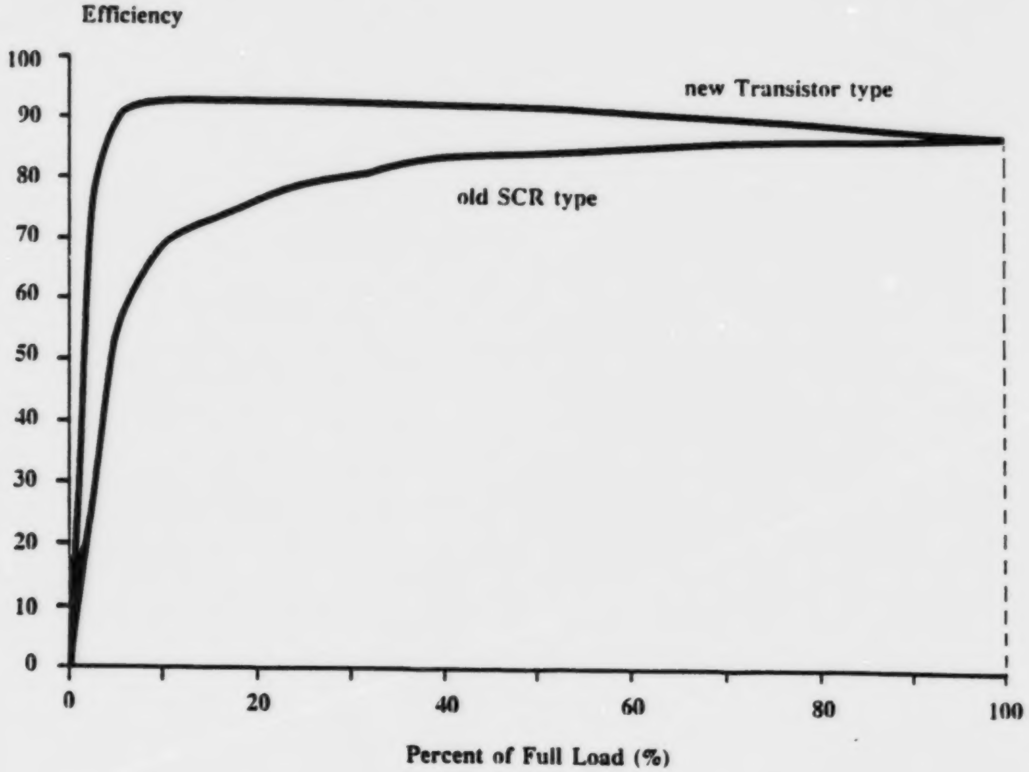


Figure 7.1: Inverter Efficiency

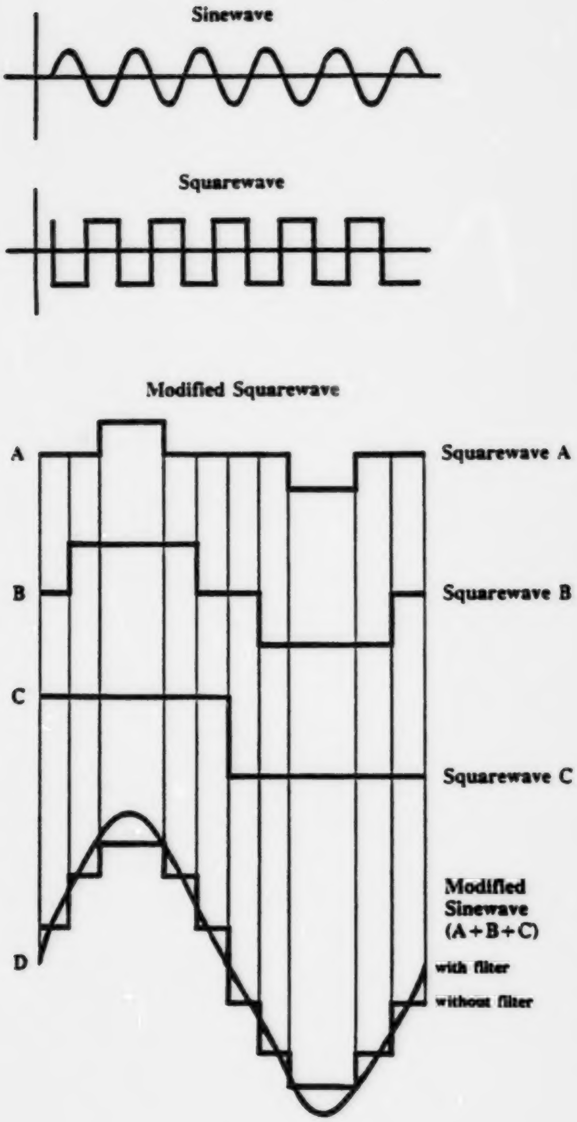
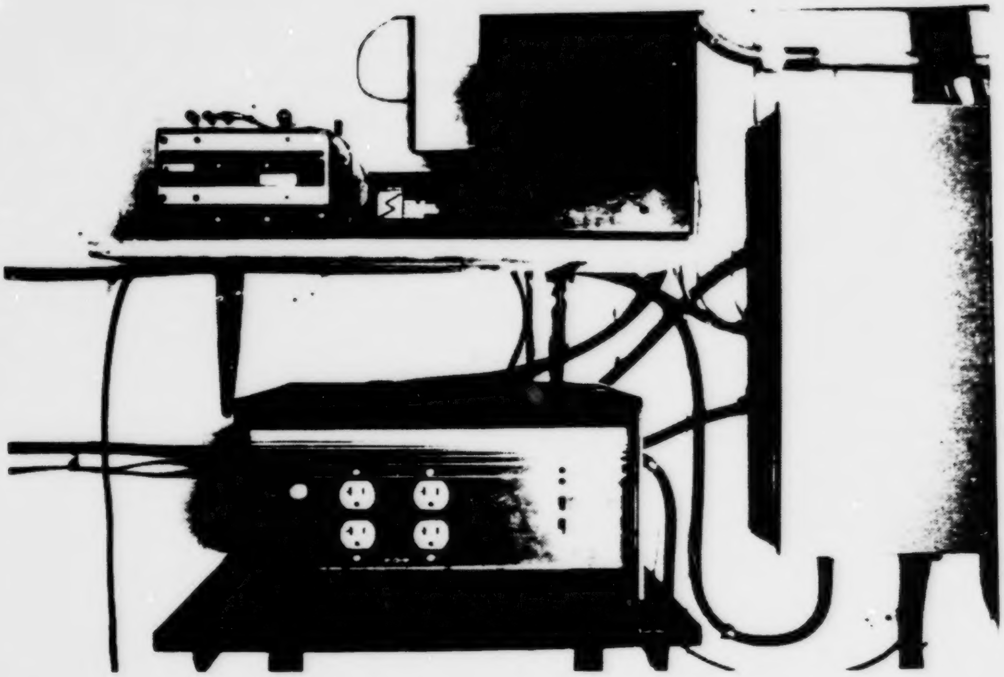

Sinewave
Squarewave
Modified Squarewave
A
Squarewave A
B
Squarewave B
C
Squarewave C
Modified Sinewave (A+B+C)
D
with filter
without filter

Figure 7.2: Inverter Waveforms



A Typical Inverter

7.4 Maximum Power Point Trackers and Array Switchers

A Maximum Power Point Tracker (MPT) is an electronic device used to maintain the operating voltage of the array at the maximum power voltage, independent of changes in load impedance and changes in array operating conditions due to temperature and insolation changes. Thus it operates essentially as an impedance matching circuit. An MPT greatly increases the efficiency of the array, but it also consumes some power itself.

Figure 7.3 illustrates how a maximum power point tracker adjusts array voltage and current independently of the load to obtain the maximum power output on the photovoltaic module I-C curve as conditions change. Figure 7.4 shows how an MPT increases daily energy production.

An array switcher is a device which can reconfigure the series/parallel arrangement of the modules in response to load or sunlight conditions. Array switchers are useful in a water pumping application to provide the high starting current required by the motor early in the morning when insolation levels are lower. For example, an array switcher could switch an array normally consisting of two strings of nine modules each, to three strings of six modules each. This latter configuration would supply the same current as the first under lower insolation conditions (660 W/m2 vs. 1000 W/m2), although at a greatly reduced voltage.

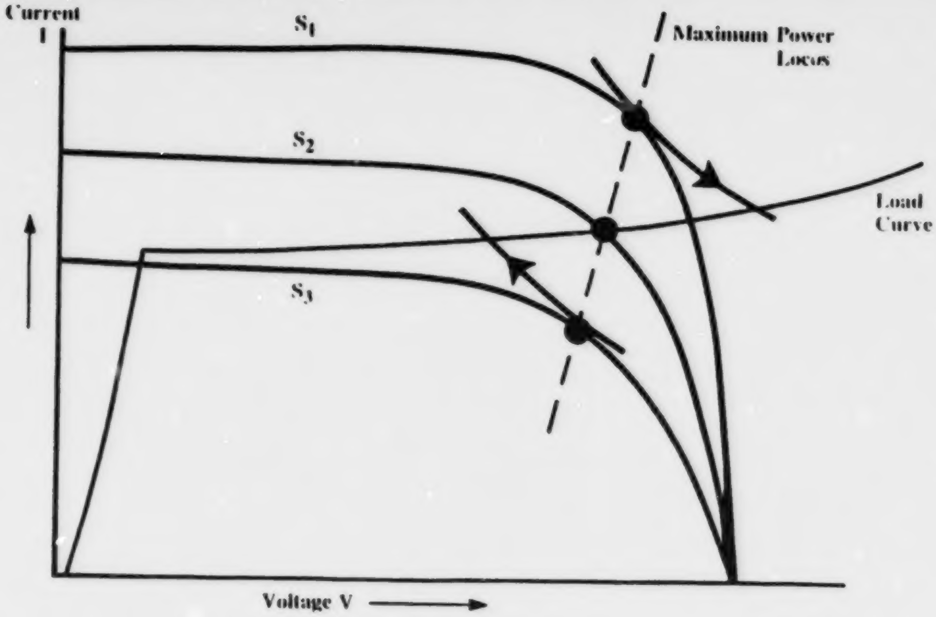


Figure 7.3: Effect of MPT on I-V Curve

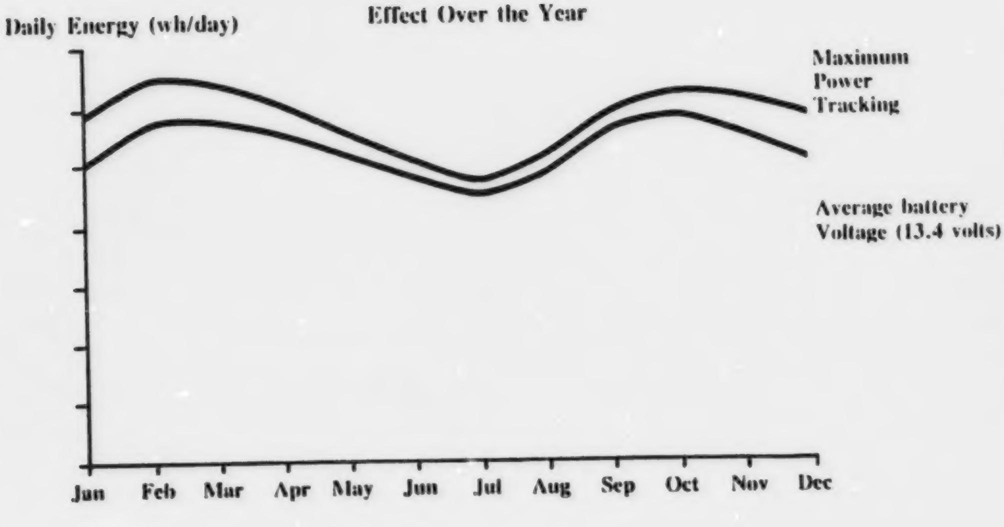


Figure 7.4: Effect of MPT on Daily Energy Production

7.5 Load Management Controller

Load management is a control feature which is frequently an option on power conditioning hardware such as a battery charge regulator or inverter. There are two normal forms of load management control.

The first cuts off loads from the battery in a pre-set sequential order as the battery voltage drops. This can be accomplished by including two or more low voltage disconnect switches with different set points, and then connecting the loads to the appropriate disconnect switch.

The second method involves the timed loads. This can be as simple as "locking out" a heavy load from coming on when another heavy load is already on, or enforcing short duration or intermittent use of some loads under specified conditions. The locking out provision may be used in order to allow a smaller inverter to handle a mixed load which incorporates two large loads, and would be in effect at all times. The timed use provision would normally only be activated when the battery state-of-charge is low, and would apply to lower priority loads or loads which could operate effectively on an intermittent basis.

CHAPTER 8

AUXILIARY POWER SYSTEMS

Although battery storage can be used to match the generation of power from a photovoltaic array with the system demand, auxiliary systems may be required to ensure sufficient power, especially in larger systems.

Standby power systems are designed to supply critical loads when photovoltaic systems exhaust their storage capacity. Hybrid systems are designed to routinely use both photovoltaic and auxiliary power systems. Photovoltaics are sometimes used only as a fuel-saver for a prime power source, while in other systems a combination of photovoltaic and other power sources is used to charge a common battery bank.

8.1 Backup Power Systems

Power interruptions can be caused by accidents, lack of sunlight, vandalism, maintenance downtime, failure of the battery storage, or a number of other reasons. Photovoltaic systems usually incorporate a backup system only if the load is critical. Loads can be classified as critical, essential or convenient, with the need for a backup power supply based on the necessity for continued service under each classification.

Preventive maintenance will reduce the failure rate of any system, while an inventory of spare parts will help to minimize inevitable down time. When generators are used, fuel storage and maintenance are primary concerns.

Diesel and gasoline engines are the most common back-up source for larger applications. Propane powered thermoelectric generators are sometimes used for low-power applications.

TABLE 8.1

RECOMMENDED BACK-UP SYSTEMS FOR VARIOUS APPLICATIONS

	Unattended		Attended	
Application	Critical	Noncritical	Critical	Noncritical
Radio	Battery and Alarm	None	Battery	None
Lighting	Battery and Alarm	None	Engine	None
Pump	Battery and Alarm	None	Engine	None
Refrigerator	Battery and Alarm	None	Engine	None
TV Battery and Alarm	None	Battery	None	
Cathodic Protection	Battery and Alarm	None	Battery and Alarm	None
Field Instruments	Battery and Alarm	None	Engine, Battery and Alarm	None

8.2 Hybrid Systems

The larger the percentage of time that power must be available from a PV system, the greater the cost, since the PV array must be oversized to support the load under worst-case weather conditions. As loads increase from about 1 KWh/day to 10 KWh/day and above, the cost of oversizing can become appreciable, and it becomes uneconomical at current prices to use solar-only system, especially in high latitudes. In a hybrid system the conventional generator replaces the oversized, poorly used segments of photovoltaic only system, while the solar component reduces the fuel use and operation and maintenance costs of the generator. Properly designed combined systems overcome the major liabilities of each and accentuate the best features of each.

The following guidelines are used to determine whether to use a hybrid system:

- Based on array/load ratio: the array to load ratio is an indication of insolation variability. The higher the array/load ratio, the more cost-effective it is to use a hybrid system. See Figure 8.1
- Based on required system availability: a photovoltaic system with an array designed to meet load power, together with one day of storage, has an average availability of approximately 94%. Where availability must be significantly higher, a hybrid system is desirable, since the photovoltaic array would otherwise have to be increased dramatically.

Generally the photovoltaic part of the system must be able to meet all the load for some period. This means the other power source (e.g. diesel) will operate as close to fixed output as possible (most efficient operation), and will not be cycled on and off too frequently. (Diesel has lower efficiency during start up and for about 30 minutes thereafter). Since photovoltaic system output seldom matches the load profile, enough storage to meet the load for between 1 to 4 days is commonly used.

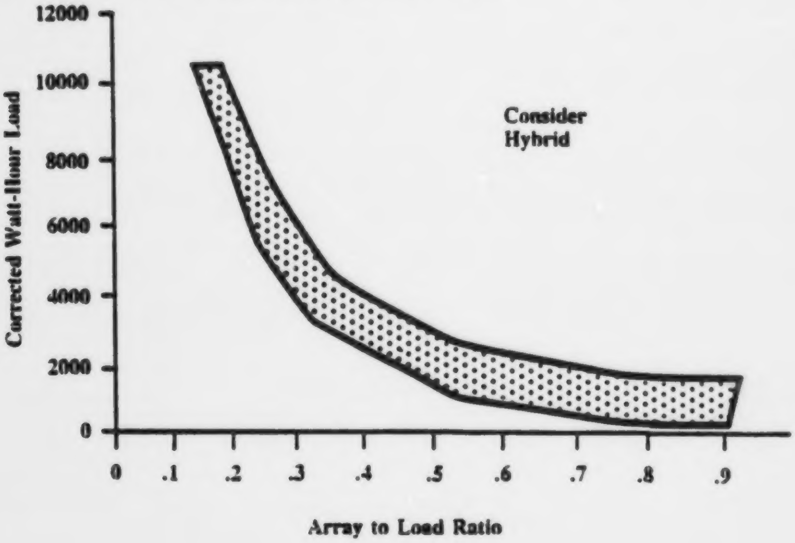


Figure 8.1: Hybrid System Indicator

8.3 Common Types of Auxiliary Power System

Engine Generator Sets:

Engine generator sets can supply power within a few seconds of switching, and may be fuelled by diesel, gasoline, or propane. The larger units are more reliable and offer lower engine speed for continuous power supply. The smaller units are usually gasoline-driven and offer faster start-up and lower initial cost, but are more prone to gasoline storage concerns and higher maintenance.

Diesel is more efficient than fuel for other heat engines, and costs less than gasoline. The torque produced in the engine is relatively constant with varying speed, and the unit does not require spark plugs. However, diesel engines represent a greater initial cost than gasoline engines and have greater weight for comparable horsepower levels. The efficiency of a generator set can be optimized by designing in a waste heat recovery system. An extended run lube oil sump is recommended at unattended sites and to reduce engine maintenance. The genset should be sized to ensure average operating load exceeds 50% of the unit's capacity to prevent excessive lube oil consumption and degraded performance.

Thermoelectric Generators:

In thermoelectric generators, power generation is based on the thermocouple effect. An electrical current will flow through a loop linking different metals when the metal junctions are maintained at different temperatures. Propane is used to heat one junction while the other is maintained at ambient temperature. Conversion efficiencies of up to 8% can be achieved, and there are no moving parts. Optimized for high conversion efficiency with low voltage and high current outputs per unit, thermoelectric generators are suitable for remote areas where frequent servicing is not practical.

SECTION C

SYSTEM DESIGN AND INSTALLATION

INTRODUCTION (SECTION C)

The final 8 chapters in this manual cover the sizing of photovoltaic systems, the selection of components for different applications, and describe how to install and maintain them. It assumes that the reader has already read Sections A and B and is familiar with how solar cells work and the components of a photovoltaic system.

Chapter 9 shows how to analyze the electrical load that the photovoltaic system is to meet.

Chapter 10 provides a step-by-step sizing procedure for a photovoltaic system using a series of worksheets. Worked examples are provided for several types of systems including a radio repeater, a water pump, and remote lodge (hybrid photovoltaic/diesel).

Chapter 11 provides guidelines for selecting system components.

Chapters 12 and 13 show how to estimate the performance of the selected system and how to evaluate its economic viability against alternatives.

Chapter 14 covers installation, testing and commissioning of photovoltaic systems.

Chapters 15 and 16 cover maintenance and performance monitoring respectively.

CHAPTER 9

LOAD ANALYSIS FOR STAND-ALONE SYSTEMS

9.1 Identifying Loads

In stand alone photovoltaic systems the electrical load defines the size of each component. It also determines whether an autonomous (solar only) system should be used or whether a hybrid system with diesel or other back-up is needed. The most important features of the load are its peak power requirement, its surge current when starting up, and its daily energy use. It is also useful to know how the load varies throughout the day and during different seasons of the year.

The load is the sum of the individual power demands from each piece of equipment and appliance, which may operate at different voltages and times of the day. The equipment or appliance may also be DC or AC. It is useful to analyze the load by grouping these individual loads by type and voltage. Basic supply system characteristics such as system voltage, array size and tilt, battery size, etc. are then based on this analysis of the load.

Table 9.1 gives sample load analyses for several common photovoltaic applications. Note the differences between summer and winter in some applications. Note also the use of the most efficient electrical technologies, and the absence of large electrical loads that could be met more cost-effectively by other energy sources such as propane or wood. (see Sidebar).

TABLE 9.1

SAMPLE LOAD ANALYSIS FOR PHOTOVOLTAIC APPLICATIONS

Application	Loads	AC/DC	Load Current (Amps)	Load Voltage (Volts)	AC Load (Watts)	DC Load (W)	Daily Duet Cycle (Hr/Day)	Weekly Duty Cycle (Day/Wk)	Power Conditioning Efficiency	Nominal Voltage (Volts)	Amp-Hour Load (AH/Day)
Communications Radio	Microwave	DC	5	24	-	120	24	7	1.0	24	120
VHF Radio		DC	15	12	-	180	10	7	0.8	24	94
Monitoring	Sensor	DC	0.5	12	-	6	15	7	1.0	12	7.5
	Heater (Winter)	DC	1.0	12	-	12	20	7	1.0	12	20
	Heater (Sp/Fall)	DC	1.0	12	-	12	10	7	1.0	12	10
Refrigeration	DC Unit	DC	10	12	-	120	7	7	1.0	12	70
	AC Unit	AC	16	120	2000	-	7	7	0.85	24	686
Lighting	4 x Incandescent	DC	1.5	24	-	144	6	7	1.0	24	36
	4 x Fluorescent	AC	1.3	120	160	-	6	7	0.85	24	47
Water Pumping	DC Unit	DC	2.0	24	-	48	6	7	1.0	24	12
	AC Unit	AC	9.5	105	-	-	6	7	0.85	24	294
Residence	4 x Lights	DC	1.5	24	-	144	4	7	1.0	24	24
	Television	AC	1.0	120	120	-	1	6	0.85	24	5
	Vacuum	AC	2.5	120	300	-	2	1	0.85	24	4.2
	Toaster Oven	AC	10	120	1200	-	2	7	0.85	24	118
	Well Pump	AC	12	240	2880	-	1	7	0.85	24	141

Sidebar: Photovoltaic Energy is Expensive. Use it wisely.

The cost of photovoltaic electricity is much higher than conventional grid power. If choices can be made on the type of equipment or appliance that can be used in the load, specify the most efficient and cost effective. Some loads are also more cost-effectively met by other energy sources.

DC or AC:	Power is lost in the conversion from DC to AC. Where possible, use DC lighting and appliances.
Lighting:	Fluorescent lighting is more than 3 times as efficient as incandescent, and lasts up to ten times as long. Fluorescent fixtures and ballasts are available in both AC and DC and as either double-ended or compact screw-in versions. In outdoor applications, where fluorescent lamps may have start-up problems in cold weather, use metal halogen lamps.
Heating:	While small DC and AC heaters may be cost-effective for small remote equipment applications, larger heating loads are usually more cost effectively met with propane or (in residential applications) wood. Insulate areas containing instruments, so that the waste heat produced can contribute to the heating load.
Refrigeration:	Use an efficient AC refrigerator with a low ENERGUIDE rating. DC or propane refrigerators are available and might be more cost-effective for small refrigerator loads.
Other Residential Appliances	In residential applications, propane powered water heaters, dryers and ranges are recommended. Dishwashers and washing machines should be avoided if possible because of their large power demands. DC models are not available.

End of Sidebar

9.2 Estimating the Average Electrical Load

The basic procedure for estimating the average electrical load of a piece of electrical equipment or appliance is to multiply the power rating of the unit in watts by the number of hours it is used per day or per week (its "duty cycle"). This gives the average electrical consumption per day in watt-hours per day. Most photovoltaic systems operate at a nominal voltage of 12 or 24 Volts. Dividing the electrical consumption by the nominal voltage, and allowing for equipment losses (DC to AC inverter or DC to DC converter), gives the average daily load in ampere-hours per day. Table 9.1 illustrates this calculation for a number of different applications. See Section 9.3 on how to select the nominal system voltage.

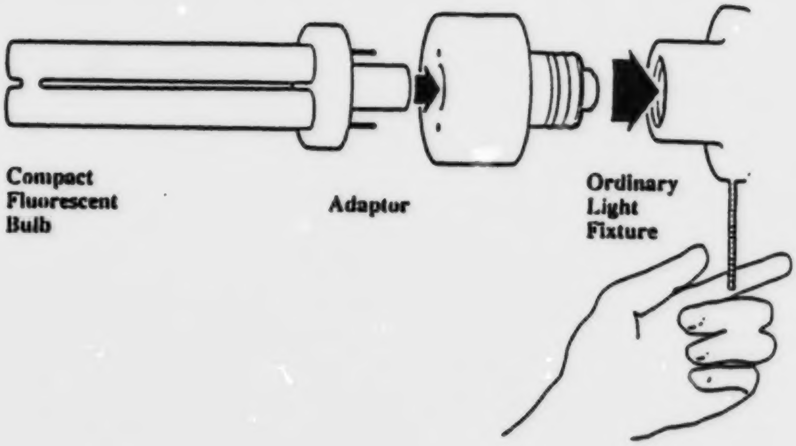
Communications and Monitoring Equipment:

These electrical loads are easy to identify. For example, a microwave repeater station might draw 5 amps at 24 Volts, 7 days a week. Its average daily load is 120 ampere-hours per day (24 hours x 5 amps = 120 amp. hours).

Lighting:

Lighting is measured in lumens, and the efficiency of a lamp is expressed in lumens per watt. Table 9.2 gives the efficiencies of several different types of lamp. Try to select the lamp on the basis of lumens, required rather than wattage using lighting manuals and estimate the electrical load as follows:

$$\text{Daily load} = \frac{\text{required lumens}}{\text{lamp efficiency}} \times \text{number of hours per day}$$



A Screw-In Fluorescent Lamp

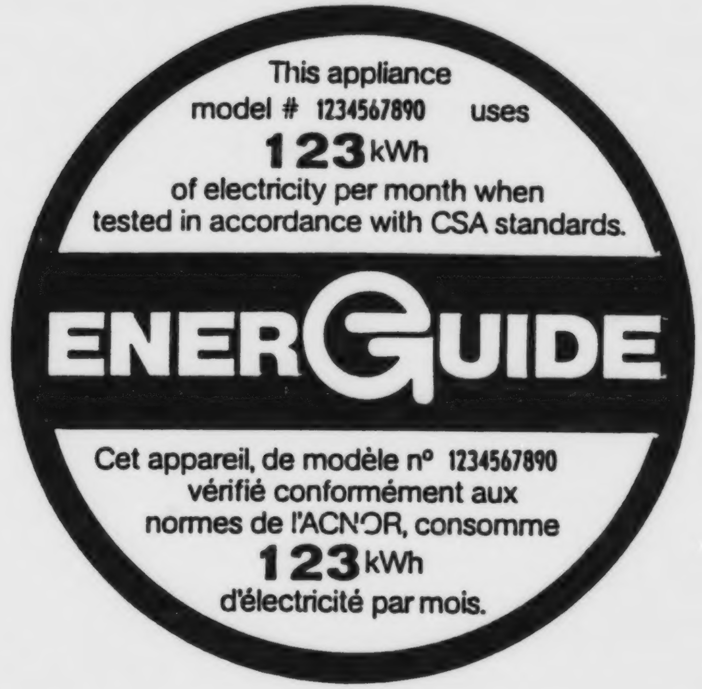
TABLE 9.2

LAMP EFFICIENCIES

Type	Lamp Efficiency (%)
Incandescent	10 - 20
Screw-in Fluorescent	40 - 60
Regular Fluorescent	50 - 70
Efficient Fluorescent	70 - 80

Appliances:

The size of loads such as refrigerators and other equipment or appliances which are automatically controlled are sometimes difficult to estimate. The duty cycle of a refrigerator, for example, depends on its compressor efficiency, how much it is used, and its panel insulation. Table 9.3 gives average daily power demands in watts hours per day for a number of common appliances based on ENERGUIDE ratings and information on typical usage collected by electrical utilities.



This appliance
model # 1234567890 uses
123 kWh
of electricity per month when
tested in accordance with CSA standards.

ENERGUIDE

Cet appareil, de modèle nº 1234567890
vérifié conformément aux
normes de l'ACNOR, consomme
123 kWh
d'électricité par mois.

The Energuide Label

TABLE 9.3

TYPICAL DAILY ELECTRICITY CONSUMPTION (Watt-hours) OF REFRIGERATOR/FREEZERS, FREEZERS AND RANGES

	Watt-hours Per Day
12 VOLT DC LOADS	
Refrigerator/freezer (high efficiency)	550
110 VOLT AC LOADS	
Freezer (15 cu.ft.)	3300
Freezer (15 cu.ft., frost free)	5000
Range (standard, 12,500 watts)	2200
Refrigerator/freezer (12 cu.ft.)	2500
Refrigerator/freezer (12 cu.ft., frost free)	4200
Refrigerator/freezer (high efficiency)	700

Other Electrical Equipment:

Table 9.4 gives the power ratings in watts of other equipment and appliances for which the duty cycle is more easily specified by the user.

TABLE 9.4

TYPICAL POWER RATINGS OF COMMON HOUSEHOLD EQUIPMENT

12 VOLT DC LOADS		Power Rating (watts)
Air compressor		60
Auto stereo		6
CB radio:	receive	3.6
	transmit	6
Clock, digital (LED)		1.2
Coffee percolator		140
Drill (1 cm)		144
Lighting:	25 watt incandescent bulb	25
	10 watt Fluorescent (15 cm screw-in)	9
	40 watt Fluorescent (1.2 m double-ended)	36
Portable heater		660 - 2000
Saw		200 - 1000
Television:	black and white	10 - 20
	colour	45 - 60
Toaster		1150
Vent fan (15 cm blade)		24
110 VOLT AC LOADS		
Block heater		500
Clock		2
Clothes washer, excluding hot water		
	wringer	300
	automatic	500
Coffee maker		900
Dishwasher, excluding hot water		1300
Drill		300
Fan, portable		115
Furnace fan motor		350
Hair dryer, portable		1000
Iron		1000
Lighting:	60 watt incandescent bulb	60
	10 watt fluorescent (15 cm screw-in)	9
	40 watt fluorescent (1.2 m double-ended)	36
Oven, microwave		1000
Personal computer(monitor and printer)		200
Radio, solid state		5
Saw		400 - 1000
Stereo		30
Television:	black and white	200
	colour	330
Toaster		1150
Vacuum cleaner, portable		800
Video cassette recorder		120

Water Pumping:

A water pump must lift water from a well or surface water, deliver this water to a storage tank or pressurized system and overcome friction losses in the piping systems. The total "head" pumped is the sum of the static, discharge and friction head.

The "Static Head" is the difference between the lowest level reached in the well or water source and the delivered height.

The "Discharge Head" is the pressure at which water is delivered (above atmospheric).

The "Friction Head" is the pressure losses exerted by the water flowing through the piping.

Most photovoltaic water pumping systems are designed to pump only when solar energy is available and deliver water to a storage tank. No batteries are needed. The important load parameters are therefore the total amount of water required per day and the maximum pumping rate (source capacity) that can be used without depleting the water source.

The electrical load is calculated either from the manufacturer's specifications for a selected pump or fan, or from the head and flow requirements. If the manufacturer does not specify the power required by the pump, then the following formula may be used to obtain the power required by the motor that drives the pump.

Power (watts) required by motor = 0.16*Q*h/Ep*Em)

where Q = flow produced by pump in litres/min
h = total head pumped in metres, equals static head plus discharge head, plus friction head
Em = efficiency of electric motor (0.70 to 0.85) at required head.
Ep = efficiency of pump (in range 0.25 to 0.65) dependent on pump size and pump design. Values in the 0.50 to 0.60 range should be used for most small single stage centrifugal pumps, and well designed positive displacement pumps. Values in the 0.25 to 0.40 range should be used for some small positive displacement pumps designed for industrial use).

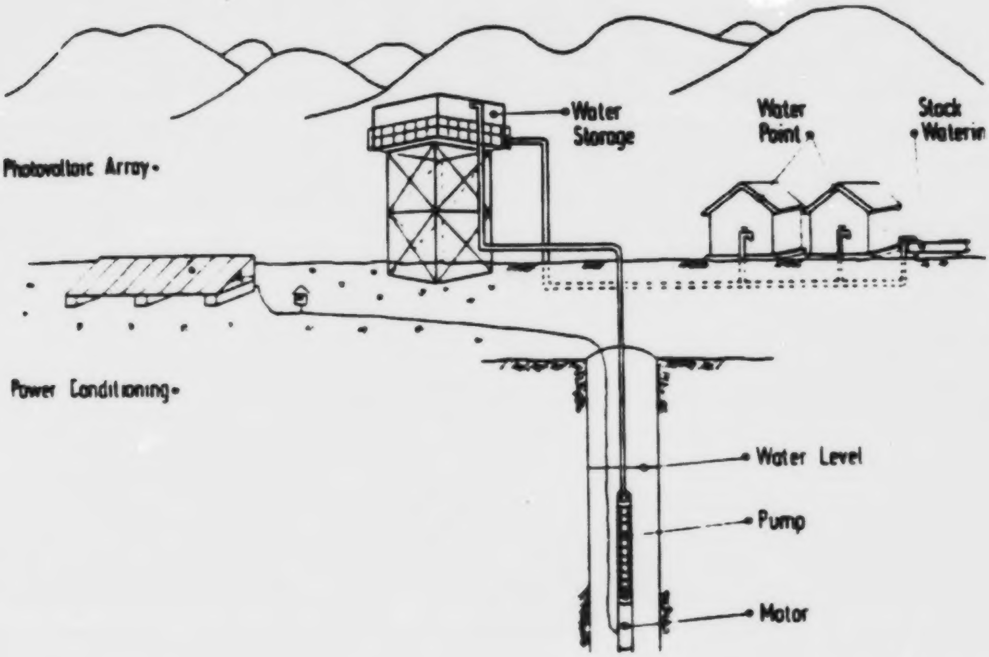
The amount of water delivered in a day of typical insolation conditions is found by multiplying the hourly flow under peak insolation conditions, times the number of peak sun hours that insolation is available - times an off peak factor (typically about 0.6) to allow for the fact that the pump operates less efficiently under lower insolation conditions.

Average daily flow (l/min) = Q * 60 * Peak Sun Hours * 0.6

Design Electrical Load (watt hours) = Power (watts) * Peak Sun Hours.

Water pumps used with photovoltaic systems are usually of the positive displacement or centrifugal type.

In positive displacement pumps, the current drawn, and hence the power required, depends on the head being pumped, and for groundwater pumping applications the head will vary from year to year and from winter to summer. These pumps will continue to pump water at heads significantly larger than the design head, but will require additional amounts of power to maintain the required water flow rate. The ability of centrifugal pumps to function on the other hand, is very head dependent, and if, for some reason, the head becomes significantly greater than the design head, the pump will stop delivering water altogether.


Water Storage
Water Point
Stock Waterin
Photovoltaic Array
Power Conditioning
Water Level
Pump
Motor

A Typical Photovoltaic Water Pumping System

9.3 Selecting the System Voltage

A good rule of thumb in selecting the system DC voltage is to consider the largest DC voltage to be supplied and use this voltage. If AC loads dominate, the DC system voltage is selected for compatibility with the inverter input. This implies selection of the inverter at an early stage in the design process.

DC loads are usually rated at 12V or multiples of 12, such as 24V, 36V, 48V, etc. Group the loads by voltage in order to select the dominant voltage, calculating the total power and maximum instantaneous power for each voltage. The voltage should be selected to maintain system current at an acceptable level. If too low a voltage is selected, the current will be high and it will be difficult to find control and regulating circuitry to handle the current. Further the size of the cables will be larger (hence increased cost) for the lower voltage. A good guideline is to keep the current in any part of the system less than 30 Amperes. For larger systems use a number of subsystems.

When AC loads dominate, the selection of voltage is defined by the size of the load and by the inverter. Inverters become more efficient as the input DC voltage is increased. Where possible the DC voltage should be multiples of 12V. Larger inverters are becoming available with 120V inputs. Others are available at 12V, 24V, and 48V. Table 9.5 provides a general guideline for inverter input voltage selection, based on AC power demand.

TABLE 9.5

Selecting System Voltage

AC Power Demand (Watts)	Inverter Input Voltage (Volts DC)
<2,000	12
2,000-5,000	24 or 48
>5,000	48 or 120

CHAPTER 10

SYSTEM SIZING

10.1 Sizing Procedure and Worksheets

This chapter describes a step-by-step procedure for sizing photovoltaic arrays, batteries, and auxiliary power systems to meet a specified electrical load, using a series of worksheets. The sizing procedure estimates the required array capacity in peak watts and required battery capacity in ampere-hours, making assumptions about the efficiency of all key system components.

Six (6) worksheets have been prepared to assist the designer with system sizing -- see Sidebar. Worked examples of three types of photovoltaic systems using the worksheets following.

Sidebar: Sizing Worksheets

Sizing Worksheet #1 Define Site Conditions

- Document mean monthly insolation data at different array tilts
- Document mean monthly ambient temperatures

Sizing Worksheet #2 Estimate Load

- Choose/define individual loads
- Define system configuration
- List individual loads and calculate total daily load
- Choose nominal voltage
- Choose type of power conditioning needed and estimate its efficiency
- Adjust load for efficiency and convert to ampere-hours per day

Sizing Worksheet #3 Size Battery Bank

- Choose deep/shallow cycle and required days of autonomy
- Derive derating factor to allow for rate of charge and ambient temperature
- Calculate required battery capacity in ampere-hours

Sizing Worksheet #4 Size Array

- Choose array tilt
- Estimate minimum insolation during operating period
- Make assumptions of array (and battery) efficiencies
- Estimate required array capacity in peak-watts
- Size Power Conditioning Components

Sizing Worksheet #5 Consider Hybrid

- Calculate array capacity/load ratio
- Determine whether hybrid is appropriate

Sizing Worksheet #6 Size Hybrid

- Resize battery
- Resize array
- Size other power source

End of Sidebar

10.1.1 Stand-alone System with Battery Storage

The suggested sizing procedure for systems with battery storage has the following major steps:

1. Define Site Conditions
2. Estimate Load
3. Size Battery Bank
4. Size Array and Power Conditioning Components
5. Determine if Hybrid System is Appropriate
6. Re-size Battery and Array and Size other Power Source.

Step 6 is only used if a hybrid system is indicated.

In general, photovoltaic systems for southern Canadian latitudes (below 55°N) should be sized to meet the specified load during the 6 to 8 week period of the year with the lowest insolation. For year round systems this is usually mid November to early January. For summer only systems, it is usually September to early October. The design number of days of autonomy will depend on the reliability required and the length of the design period. For example, if designing for the lowest month, 10 - 15 days of autonomy should be used. If designing for the lowest average insolation over a 2 to 3 month period, 15-20 days should be used. Selection of design depth of discharge will depend on the type of battery used and the required life and reliability of the system. A lower design depth of discharge will provide longer life and reliability but a higher battery cost.

Remote communications systems are prime candidates for photovoltaics power. These include radio transmitters and radio/microwave repeater stations, particularly those which are not accessible for most of the year. The following is an example of such a photovoltaic system deployed in an Alberta repeater station.

Sizing Worksheet #1 - Site Conditions

Location:	Edmonton, Alta.
Latitude :	53°N
Longitude:	113°W

Load:
Transmit: 180 Watts for 10 hours per day
Receive: 40 Watts for 10 hours per day
Standby: 4 Watts for 4 hours per day

System Voltage:	12 Volts
Operation:	Year Around, 7 days per week
Lowest Average Temperature:	-16°C

Sizing Worksheet #2 - Load Analysis

Using the load analysis portion of worksheet #2 the total load is 2216 Watt-hours per day. Since the nominal system voltage is 12 Volts and no inverter or converter is required, this translates into 185 AH/day.

Sizing Worksheet #3 - Battery Sizing

For this system a deep cycle battery which discharges to 20% of its rated capacity over 15 days is recommended (DOD = 0.80). Since the inaccessible period is during the winter, the system is designed for operation in this period, when the average temperature is -16°C. Thus the low temperature battery derating factor for the 500 hour discharge rate is 0.72. Applying this factor to the battery sizing portion of the worksheet gives a required battery size of 4818 AH at 12V nominal.

Sizing Worksheet #4 - Array Sizing

For this application where autonomy during the winter is the prime consideration, the array should be tilted at Latitude + 15 = 68^0 to maximize solar collection, and to allow snow to easily slide off the array. From Worksheet #1, the lowest average peak sunlight hours occurs during the November to January period (9.07 MJ/m^2 or 2.5 peak sun hours per day). Allow for an efficiency of 0.90 for the charge regulator, and 95% for possible losses due to dirt on the modules. In this application, the efficiency of the battery must also be taken into account. More energy must be supplied to the battery to ensure the required load current is met. Using a battery efficiency of 85%, the required array size is 1220 peak watts and array current 102 amps.

SIZING WORKSHEET #1: DEFINE SITE CONDITIONS

RADIO REPEATER

SYSTEM LOCATION: EDMONTON	LATITUDE: 53°N	LONGITUDE: 113°W
INSOLATION LOCATION #1: EDMONTON INTERNATIONAL	LATITUDE: 53°N	LONGITUDE: 113°W
INSOLATION LOCATION #2:	LATITUDE:	LONGITUDE:

MONTH	AMBIENT TEMPERATURE	INSOLATION AT TILT = LAT. - 15 deg.		INSOLATION AT TILT = LAT.		INSOLATION AT TILT = LAT. + 15 deg.	
	Degrees C	(MJ/m2. day)	(Peak Sun Hours)	(MJ/m2. day)	(Peak Sun Hours)	(MJ/m2. day)	(Peak Sun Hours)
Jan.	-16.5					11.50	3.2
Feb.	- 11.4					14.98	4.2
Mar.	-6.7					18.19	5.0
Apr.	3.2					18.38	5.1
May	10.1					16.83	4.7
June	14.1					15.73	4.4
July	15.8					16.97	4.7
Aug.	14.8					17.84	5.0
Sept.	9.8					16.28	4.5
Oct.	4.7					14.82	4.1
Nov.	-5.5					11.22	3.1
Dec.	- 13.1					9.07	2.5

SIZING WORKSHEET #2: ESTIMATE LOAD

LOAD DESCRIPTION	AC & DC	LOAD CURRENT (amps)	LOAD VOLTAGE (volts)	AC LOAD (watts)	INVERTER EFFICIENCY (%)	DC LOAD (watts)	DUTY CYCLE (hrs/day)	DUTY CYCLE (days/wk)	DAILY LOAD (watt-hrs)	NOMINAL VOLTAGE (volts)		AMP-HOUR LOAD (ah/day)
TRANSMIT	DC					180	10	7	1800	12		150
RECEIVE	DC					40	10	7	400	12		33
STANDBY	DC					4	4	7	16	12		2
TOTAL						180			2216			185

DESIGN LOAD (Total ampere-hour load)	185	AH/DAY
DESIGN PEAK CURRENT DRAW $\frac{\text{(DC load)}}{\text{(Nominal Voltage)}}$	18.75	AMPS

SIZING WORKSHEET #3: SIZE BATTERY BANK

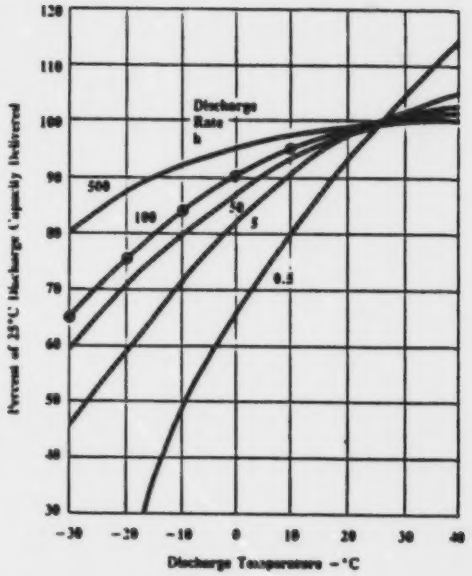
AMP-HOUR LOAD (amp-hrs/day)	X	DAYS OF AUTONOMY (days)	/	MAX. DEPTH OF DISCHARGE (fraction)	=	USABLE BATTERY CAPACITY (amp-hrs)
185	X	15	/	0.80	=	3469

OPERATING TEMP. = -16.5 (degrees C)

DISCHARGE RATE = 24 x DAYS OF AUTONOMY

= 360 (HRS)

USABLE BATTERY CAPACITY (amp-hrs)	/	USABLE FRACTION OF CAPACITY AVAILABLE (from graph)	=	DESIGN BATTERY CAPACITY (amp-hrs)
3469	/	0.72	=	4818



SIZING WORKSHEET #4: SIZE ARRAY & PV COMPONENTS

OPERATING SEASON	12	Months
ARRAY TILT	53 + 15 = 68	Latitude + or - Degrees
LOWEST SOLAR RADIATION IN OPERATING SEASON (DESIGN PEAK SUN HOURS)	2.5	Peak Sun Hours

AMP-HOUR LOAD (amp-hrs/day)	/	LOWEST PEAK SUN HOURS (hrs/day)	/	MODULE LOSS FACTOR (fraction)	/	CHARGE REGULATOR EFFICIENCY (fraction)	/	BATTERY EFFICIENCY (fraction)	=	DESIGN ARRAY CURRENT (amps)
185	/	2.5	/	0.95	/	0.90	/	0.85	=	102

DESIGN ARRAY CURRENT (amps)	X	NOMINAL VOLTAGE (volts)	=	DESIGN ARRAY POWER (peak-watts)
102	X	12	=	1220

DESIGN ARRAY CURRENT (amps)	=	DESIGN POWER CONDITIONER CURRENT (amps)
102	=	102

10.1.2 Stand-Alone Systems Without Storage

Photovoltaic system applications without battery storage usually involve simple single source loads such as pumps and fans where either storage can be better met non electrically (e.g. water storage) or energy is only needed during the day (e.g. ventilation fans).

The sizing procedure differs from that followed for systems with batteries in that the electrical load is determined as much by the available solar radiation as by the load. There is also, of course, no battery sizing required:

1. Define Site Conditions
2. Estimate Load
3. Size Array and Power Conditioning Components

Because there is no battery, the array must be sized to meet the load under peak insolation conditions. The duty cycle is equal to the number of hours of peak sunshine during the least sunny month of the operating season.

The following example describes the procedure for sizing the photovoltaic array for a water pumping system, assuming that the power requirements are equal to the rated size of the motor supplied with the pump.

Sizing Worksheet #1 - Site Conditions

Location: Vancouver, B.C.
Latitude : 49^0N
Longitude: 123^0W

Load: An average of 9 m^3/day delivered against a total head of 17 metres by a DC pumping system with nominal capacity 50 litres/min and subsystem efficiency (motor and pump) of 55%.

System Voltage: 12 Volts.

Operation: When solar energy available, summer only.

Operating Temperature: 15°C

Sizing Worksheet #2 - Load Analysis

The number of peak sun hours in the least sunny month is 4.9, therefore the duty cycle is 5 hours.

Small single stage centrifugal pumps are designed for medium to low head operation, and pump medium to large flow rates. The power required for operation of a given pump is known approximately, and may be obtained from the manufacturer. Assume that the manufacturer's data shows that a 1/3 HP pump delivers 50 litres/min when operating the required head.

At a head of 17m, an efficiency of 55% and nominal capacity of 50 litres/min, the required pump power is 250 watts. The average daily load is, therefore, 1250 watt hrs. At 12 volts this is equivalent to 104 ampere hours per day.

The average daily water flow is 50 x 60 x 5 x 0.6 = 9,000 litres or 9 m^2/day.

Sizing Worksheet #4 - Array Sizing

Since summer only operation is required, use a tilt equal to Latitude = 49^0. From Worksheet #1, the lowest average peak sunlight hours at this tilt occurs in September (17.55 MJ/m^2 or 4.9 peak sunlight hours per day). Assuming a power conditioner efficiency of 90% and 10% array losses; the design array size is therefore 26.2 amps or 314 peak watts.

SIZING WORKSHEET #1: DEFINE SITE CONDITIONS

WATER PUMP

SYSTEM LOCATION: VANCOUVER	LATITUDE: 49°N	LONGITUDE: 123°W
INSOLATION LOCATION #1: VANCOUVER INTERNATIONAL	LATITUDE: 49°N	LONGITUDE: 123°W
INSOLATION LOCATION #2:	LATITUDE:	LONGITUDE:

MONTH	AMBIENT TEMPERATURE	INSOLATION AT TILT = LAT. - 15 deg.		INSOLATION AT TILT = LAT.		INSOLATION AT TILT = LAT. + 15 deg.	
	Degrees C	(MJ/m2. day)	(Peak Sun Hours)	(MJ/m2. day)	(Peak Sun Hours)	(MJ/m2. day)	(Peak Sun Hours)
Jan.	2.5			5.47	1.5		
Feb.	4.6			9.74	2.7		
Mar.	5.8			13.17	3.7		
Apr.	8.8			16.18	4.5		
May	12.2			18.85	5.2		
June	15.1			18.36	5.1		
July	17.3			20.63	5.7		
Aug.	17.1			18.69	5.2		
Sept.	14.2			17.55	4.9		
Oct.	10.0			10.82	3.0		
Nov.	5.9			6.47	1.8		
Dec.	3.9			4.86	1.3		

SIZING WORKSHEET #2: ESTIMATE LOAD

LOAD DESCRIPTION	AC & DC	LOAD CURRENT (amps)	LOAD VOLTAGE (volts)	AC LOAD (watts)	INVERTER EFFICIENCY (%)	DC LOAD (watts)	DUTY CYCLE (hrs/day)	DUTY CYCLE (days/wk)	DAILY LOAD (watt-hrs)	NOMINAL VOLTAGE (volts)		AMP-HOUR LOAD (ah/day)
Pump	DC					250	5	7	1250	12		104.0
TOTAL						250			1250			104.0

DESIGN LOAD (Total ampere-hour load)	104.0	AH/DAY
DESIGN PEAK CURRENT DRAW $\frac{\text{(DC load)}}{\text{(Nominal Voltage)}}$	20.8	AMPS

SIZING WORKSHEET #4: SIZE ARRAY & PV COMPONENTS

OPERATING SEASON	MAY To SEP	Months
ARRAY TILT	49°	Latitude + or - Degrees
LOWEST SOLAR RADIATION IN OPERATING SEASON (DESIGN PEAK SUN HOURS)	4.9	Peak Sun Hours

AMP-HOUR LOAD (amp-hrs/day)	/	LOWEST PEAK SUN HOURS (hrs/day)	/	MODULE LOSS FACTOR (fraction)	/	CHARGE REGULATOR EFFICIENCY (fraction)	/	BATTERY EFFICIENCY (fraction)	=	DESIGN ARRAY CURRENT (amps)
104	/	4.9	/	0.9	/	0.9	/	N/A	=	26.2

DESIGN ARRAY CURRENT (amps)	X	NOMINAL VOLTAGE (volts)	=	DESIGN ARRAY POWER (peak-watts)
26.2	X	12	=	314

DESIGN ARRAY CURRENT (amps)	=	DESIGN POWER CONDITIONER CURRENT (amps)
26.2	=	26.2

10.1.3 Hybrid Systems

This section provides an example of a remote lodge system where a photovoltaic array is used as the prime source of power, minimal battery storage is employed, and a diesel generator set is used to make up power when the battery becomes discharged.

Several approaches can be used to choose a photovoltaic/diesel mix for a hybrid system:

- One approach is to choose a given number of modules, size the battery storage and the generator, then determine the operation sequence and resultant economics.
- A second approach is to size the system assuming that photovoltaics will provide a given percentage of the system power or for a portion of the year.
- A third approach is to design the photovoltaic part of the system for a given power output (which may not correspond to the actual load) and then design the storage and generator to ensure that the load is supplied at all times.
- A fourth approach is used when a photovoltaic system is being designed for use with an existing diesel or other power system. In this case, the array is sized to meet a portion of the load with the restriction that the other power system must not be run under conditions where its efficiency is impaired (e.g., diesel under low load).

The second approach is used in the following example. In each case use a design battery days of autonomy of 1 to 5 days.

Sizing Worksheet #1 - Site Conditions

Location: Vancouver, B.C.
Latitude: 49^0N
Longitude: 123^0W
Load : Lights (4 x 40 Watts) DC
Pump (900 Watts) DC
Refrigerator (2000 Watts) AC
Microwave (750 Watts) AC
Toaster (1000 Watts) AC

System Voltage : 120 AC/48 DC

Operation : Year round, 7 days per week
Lowest Average Temp.: 2.5°C

Auxiliary Power : Diesel or gasoline generator

Sizing Worksheet #2 - Load Analysis

Using typical duty cycles for the loads from Tables 9.3 and 9.4 and an 85% inverter efficiency, the total load at a 48 Volt nominal voltage is 151 AH/day or 7250 watt hours/day.

Sizing Worksheet #3 - Size Battery Bank

For a photovoltaic only system, assume 12 days storage and deep-cycling. Assume also that the battery is in a heated space at 25°C. The derating factor is therefore 0.9. The required capacity is 2516 AH total capacity.

Size Worksheet #4 - Size Array

For year round use, a tilt of latitude $+15^0C = 68^0$ should be specified. From Worksheet #1, the minimum monthly average solar radiation is 5.14 MJ/m^2 (1.4 peak sun hours per day) in December. The required array size at an array efficiency of 0.9 and battery efficiency of 0.85, is 7520 peak watts.

Sizing Worksheet #5 - Consider Hybrid

The array to load ratio is 1.04 and a hybrid is recommended.

Sizing Worksheet #6 - Size Hybrid

Assume array is sized to meet load between May and September. From Worksheet #1, the new design minimum peak sun hours at a tilt equal to latitude is 4.9 (17.55 MJ/m^2) per day. The required array size for the hybrid system is 2150 peak watts. The battery and generator must be sized so that they can make up the shortfall in the month with the lowest insolation (December). In December the average insolation at the new tilt is 1.3 peak sun hours (4.86 MJ/m^2). The array will therefore meet 34% of the load. Assume that only 1 day of autonomy is required and that the generator must charge the battery in 4 hours. The required battery size under these conditions is 210 AH and the required generator size is 1650 watts, assuming a rectifier efficiency of 80%.

SIZING WORKSHEET #1: DEFINE SITE CONDITIONS

REMOTE RESIDENCE

SYSTEM LOCATION: NEAR VANCOUVER	LATITUDE: 49°N	LONGITUDE: 123°W
INSOLATION LOCATION #1: VANCOUVER INTERNATIONAL INSOLATION LOCATION #2:	LATITUDE: 49°N LATITUDE:	LONGITUDE: 123°W LONGITUDE:

MONTH	AMBIENT TEMPERATURE	INSOLATION AT TILT = LAT. - 15 deg.		INSOLATION AT TILT = LAT.		INSOLATION AT TILT = LAT. + 15 deg.	
	Degrees C	(MJ/m2. day)	(Peak Sun Hours)	(MJ/m2. day)	(Peak Sun Hours)	(MJ/m2. day)	(Peak Sun Hours)
Jan.	2.5			5.47	1.5	5.71	1.6
Feb.	4.6			9.74	2.7	9.90	2.8
Mar.	5.8			13.17	3.7	12.72	3.5
Apr.	8.8			16.18	4.5	14.80	4.1
May	12.2			18.85	5.2	16.47	4.6
June	15.1			18.36	5.1	15.71	4.4
July	17.3			20.63	5.7	17.69	4.9
Aug.	17.1			18.69	5.2	16.73	4.6
Sept.	14.2			17.55	4.9	16.68	4.6
Oct.	10.0			10.82	3.0	10.77	3.0
Nov.	5.9			6.47	1.8	6.67	1.9
Dec.	3.9			4.86	1.3	5.14	1.4

SIZING WORKSHEET #2: ESTIMATE LOAD

LOAD DESCRIPTION	AC & DC	LOAD CURRENT (amps)	LOAD VOLTAGE (volts)	AC LOAD (watts)	INVERTER EFFICIENCY (%)	DC LOAD (watts)	DUTY CYCLE (hrs/day)	DUTY CYCLE (days/wk)	DAILY LOAD (watt-hrs)	NOMINAL VOLTAGE (volts)		AMP-HOUR LOAD (ah/day)
4 x 40 watt LIGHTS	DC	3.3	48			160	4	7	640	48		13
PUMP	DC	18	48			900	3	7	2700	48		56
FRIDGE	AC	16.7	120	2000	0.85	2353	-	-	2500*	48		52
MICROWAVE	AC	6.25	120	750	0.85	882	1	7	882	48		18
TOASTER	AC	8.3	120	1000	0.85	1176	0.5	7	588	48		12
									*ENERGUIDE			
TOTAL						5471			7310			151

DESIGN LOAD (Total ampere-hour load)	151	AH/DAY
DESIGN PEAK CURRENT DRAW $\frac{\text{(DC load)}}{\text{(Nominal Voltage)}}$	114	AMPS

SIZING WORKSHEET #3: SIZE BATTERY BANK

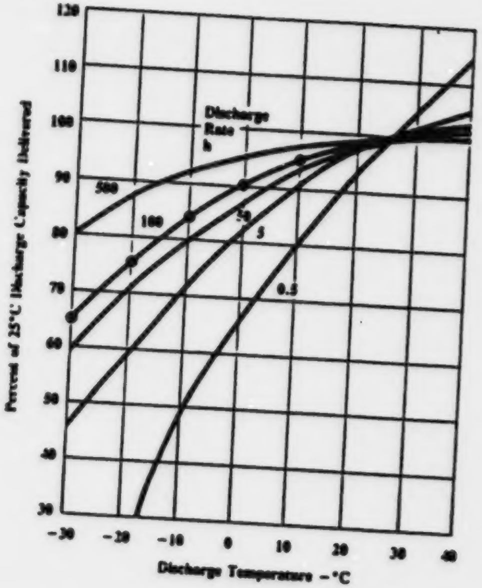
AMP-HOUR LOAD (amp-hrs/day)	X	DAYS OF AUTONOMY (days)	/	MAX. DEPTH OF DISCHARGE (fraction)	=	USABLE BATTERY CAPACITY (amp-hrs)
151	X	12	/	0.8	=	2265

OPERATING TEMP. = 25 (degrees C)

DISCHARGE RATE = 24 x DAYS OF AUTONOMY

= 288 (HRS)

USABLE BATTERY CAPACITY (amp-hrs)	/	USABLE FRACTION OF CAPACITY AVAILABLE (from graph)	=	DESIGN BATTERY CAPACITY (amp-hrs)
2265	/	0.9	=	2516



SIZING WORKSHEET #4: SIZE ARRAY & PV COMPONENTS

OPERATING SEASON	12	**Months**
ARRAY TILT	49 + 15 = 64°	**Latitude + or - Degrees**
LOWEST SOLAR RADIATION IN OPERATING SEASON (DESIGN PEAK SUN HOURS)	1.4	**Peak Sun Hours**

AMP-HOUR LOAD (amp-hrs/day)	/	LOWEST PEAK SUN HOURS (hrs/day)	/	MODULE LOSS FACTOR (fraction)	/	CHARGE REGULATOR EFFICIENCY (fraction)	/	BATTERY EFFICIENCY (fraction)	=	DESIGN ARRAY CURRENT (amps)
151	/	1.4	/	0.9	/	0.9	/	0.85	=	157

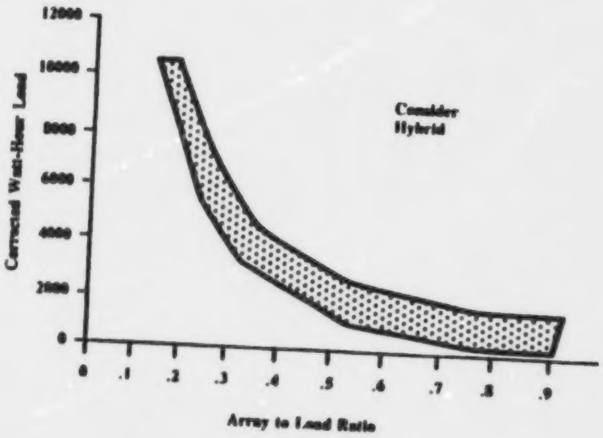
DESIGN ARRAY CURRENT (amps)	X	NOMINAL VOLTAGE (volts)	=	DESIGN ARRAY POWER (peak-watts)
157	X	48	=	7520

DESIGN ARRAY CURRENT (amps)	=	DESIGN POWER CONDITIONER CURRENT (amps)
157	=	157

SIZING WORKSHEET #5: CONSIDER HYBRID

AMP-HOUR LOAD (amp-hrs/day)	X	NOMINAL VOLTAGE (volts)	=	WATT - HOUR LOAD (watt-hrs/day)
151	X	48	=	7250

DESIGN ARRAY POWER (watt)	/	WATT - HOUR LOAD (watt-hrs/day)	=	ARRAY/LOAD RATIO
7520	/	7250	=	1.04



HYBRID DESIGN (from Graph)

YES	NO
✓	

SIZING WORKSHEET #6: SIZE HYBRID

PHOTOVOLTAIC DESIGN PERIOD	MAY TO SEPT.	Months
ARRAY TILT	49°	Latitude + or - Degrees
LOWEST SOLAR RADIATION IN DESIGN PERIOD	4.9	Peak Sun Hours

AMP-HOUR LOAD (amp-hrs/day)	/	DESIGN PERIOD PEAK SUN HOURS (hrs/day)	/	MODULE LOSS FACTOR (fraction)	/	CHARGE REGULATOR EFFICIENCY (fraction)	/	BATTERY EFFICIENCY (fraction)	=	DESIGN ARRAY CURRENT (amps)
151	/	4.9	/	0.9	/	0.9	/	0.85	=	44.8

DESIGN ARRAY CURRENT (amps)	X	NOMINAL VOLTAGE (volts)	=	DESIGN ARRAY POWER (peak-watts)
44.8	X	48	=	2150

DESIGN ARRAY CURRENT (amps)	X	LOWEST PEAK SUN HOURS	=	PV LOAD CONTRIBUTION (amp-hrs/day)
44.8	X	1.3	=	58

AMP-HOUR LOAD (amp-hrs/day)	X	DAYS OF AUTONOMY (days)	/	MAXIMUM DEPTH OF DISCHARGE (fraction)	/	USABLE FRACTION OF BATTERY CAPACITY AVAILBLE (from Worksheet #3)	=	DESIGN BATTERY CAPACITY (amp-hrs)
151	X	1	/	0.8	/	0.9	=	210

SIZING WORKSHEET #6: SIZE HYBRID (continued)

AMPERE-HOUR LOAD (amp_hr/day)	/	BATTERY EFFICIENCY (fraction)	/	RECTIFIER EFFICIENCY (fraction)	X	NOMINAL VOLTAGE (volts)	=	DESIGN GENERATOR LOAD (watt.hrs/day)
151	/	0.85	/	0.8	x	48	=	10,660

DESIGN GENERATOR LOAD (watt.hrs/day)	X	DAYS OF AUTONOMY	/	CHARGE TIME (hrs)	=	NOMINAL GENERATOR CAPACITY (watts)
10,660	x	1	/	4	=	2665

CHAPTER 11

SELECTING THE KEY COMPONENTS

Chapter 10 showed how to determine the size of batteries and arrays for photovoltaic systems. The next step is to select the key components to meet these requirements. Specify components in the following order:

1. Choose the batteries
2. Choose the modules for the array
3. Choose the necessary power conditioning equipment
4. Specify wiring and switchgear
5. Estimate overall system losses and respecify the components as required.

Descriptions of the system components themselves may be found in Section B of this manual. The following sections provide only criteria and guidelines for selecting components. Contact manufacturers directly to obtain literature on various components.

11.1 Choosing the Batteries

The required battery capacity and nominal battery (system) voltage will have been selected during the sizing process (Sizing Worksheet #3). The decision to use deep or shallow cycling will also have been made.

In general, for larger systems, lead acid batteries should be selected for reasons of initial cost. It is important to choose a quality battery well suited to the photovoltaic application, since the battery will be the key element which defines the lifetime of the system and most of the maintenance requirements. One can always add new modules to the system if necessary, but it is not generally recommended to add new batteries to an old battery bank.

- For batteries which are to be shallow cycled with long autonomy periods (50 to 500 hour discharge times) select a lead calcium battery since it is virtually maintenance free and well suited to photovoltaic applications.

- For batteries which are to be deep cycled and discharge daily, select a lead antimony deep discharge battery.

For small systems which require low capacity batteries in the 50 to 150 AH range it is possible to find single batteries with enough cells in series to give a nominal 6 or 12 Volts. A low cost option for low capacity applications is a recreational vehicle (RV) battery available in most automotive supply stores.

For larger systems several batteries will be needed. Batteries are usually available as single cell units, with each cell having a nominal 2 Volt rating with the actual voltage depending on the specific gravity of the electrolyte. A fully charged lead-acid cell will have an electrolyte with a specific gravity (at 25^0 C) in the range of 1.25 to 1.3. For low temperature, select a specific gravity at or near 1.3, while for high temperature operation select a specific gravity of the order of 1.25. Select the cell with the Ampere-hour rating nearest to that determined during the sizing procedure. Then find the number of cells to be connected in series by dividing the nominal system voltage by the nominal cell voltage (usually 2 for lead acid cells regardless of specific gravity). Generally 6 cells will be required for a 12 Volt system (Note that when the battery is being charged it will reach of the order of 2.5 Volts per cell or 15 Volts for a 12 Volt battery at 20 C).

The nominal voltage for NiCad battery cells is usually about 1.2, therefore more cells are required for a given system voltage.

Among the additional factors to be considered in choosing a battery is the lifetime of the system. Will the battery achieve the required number of cycles of charge and discharge? Also, consider the cost. It may often be cheaper to choose a battery cell of half the capacity required, and use two parallel strings. Transportation to the site is another consideration. Larger capacity batteries are bulky, heavy and difficult to handle.

Finally, some electronic loads have a restricted "voltage window" and cannot accept the high voltages necessary to charge some types of batteries (e.g. lead-calcium) in cold weather.

When making comparisons between batteries, compare capacity at the same hours of discharge and operating temperature, and compare battery life at the same depth of discharge. Use the following equation to compare effective battery cost:

$$EC = C/(AH \times CL \times V)$$

Where EC = Effective cost ($/AH. cycle. volt)
C = Cost ($)
CL = Cycle life at specified DOD (# of cycles)
AH = Ampere hour rating at specified operating temperature and discharge rate
V = Nominal voltage of battery

11.2 Choosing the Modules

In the sizing procedure presented in Chapter 10, the array size will have been determined in terms of peak watts delivered at peak sun hours. The designer must now select the actual photovoltaic module to be used, and calculate the actual number of modules to be used in the array.

Number of Modules in Parallel:

Using manufacturer's literature, choose a module with a rated current such that when the following calculation is carried out, an integral number of modules in parallel is required.

$$\text{Number of modules in parallel} = \frac{\text{Array Peak Watts}}{\text{Module Peak Amps} * \text{Nominal Voltage}}$$

Number of Modules in Series:

Again using the manufacturers literature, determine the number of modules in series by dividing the system voltage by the nominal module voltage, remembering to allow for the increased module voltage that occurs at lower temperatures. Generally for systems with battery storage, the nominal module voltage will be 12 Volts, while for systems such as pumps where the array is connected directly to the load, a nominal module voltage of 15 Volts can be used. Module voltage increases with decreasing temperature by the order of 2.4mV/oC/cell. The maximum power point of the series string of modules must be sufficient to charge the battery or operate a direct load such as a pump under all operating temperatures.

$$\text{Number of modules in series} = \frac{\text{Maximum System Voltage that will permit maximum charging current}}{\text{Module Voltage corrected for operating conditions}}$$

If two or more modules are being considered, select the type which ensures that the total load is met year round at the lowest cost.

Once the number of modules in parallel and the number in series are known, the total number is found by multiplying the two together. A good rule of thumb is to use the largest power module possible to achieve the required current while maintaining correct (temperature adjusted) voltage requirements, since this will reduce the amount of handling, and thus the installation time. Further, since it requires roughly the same amount of time and only slightly more materials to manufacture a higher power module as it does a lower power one, the module will generally cost less on a dollars/Watt basis.

Select a blocking diode for each series string. Because a blocking diode is forward biased when the array is generating power, it should be selected with the lowest forward voltage drop to minimize power losses.

11.3 Choosing the Power Conditioning Components

Proper specification and selection of the power conditioning elements is a very important aspect of photovoltaic system design. Improper selection can result in inefficiencies, faulty operation, safety hazards, inadequate performance and excessive costs. Included under the general blanket term "power conditioning" are battery charge regulators, auxiliary battery charges, controllers, DC-DC converters, maximum power point trackers and DC to AC inverters.

Battery Charge Regulators:

In virtually all photovoltaic systems with lead-acid battery storage there will be the requirement for a battery charge controller. A number of options are available to the designer, and the following general guidelines are useful:

- For small systems where the array consists of one or two modules (5 - 15 amps), the most cost effective approach is a simple shunt regulator which, once the battery is approaching full charge, shunts the current from the array across the battery through a transistor. This approach is not recommended for high power systems, since the power losses will be too high and a means to dissipate the heat generated in the transistor through a dummy load will be necessary.

- For intermediate systems where the array and load currents are typically in the range of 10 to 30 amperes, a series regulator should generally be used. These units open the path between the array and the battery when the battery reaches a state near full charge. In many units, a "trickle charge" feature is included whereby the path is periodically opened and closed to top up the battery. This is a desirable feature.

- For systems exceeding 30 Amperes it is good practice to divide the array into sub-arrays, and use a charger which has a number of channels, controlled by a master circuit. Taper charging can be achieved by switching out the sub-arrays in a planned sequence. Such units are available from number of manufacturers.

- For systems where batteries will encounter a wide range of ambient temperatures, a temperature compensation feature is recommended. This feature adjusts the beginning and end, rate charging voltage set points to properly compensate for battery ambient temperature deviation.

- To prevent batteries from being discharged too much and exposing them to damage (e.g. freezing), load control is desirable. This can be done automatically in the charge controller, when the battery discharges to a preset level. Another approach is to include a warning system in the unit so that the user may manually shed loads.

Inverters:

The inverter is generally the third largest cost item after the array and the batteries. Thus, it is important to choose the right one for the application. The following characteristics should be addresses in choosing the inverter:

- Total AC power demand (watts). Oversize the unit slightly to ensure there is enough capability. However, remember that most units operate most efficiently at or near rated capacity.

- Inverter Output Waveform. The choice depends on the type of load. A cheap square wave inverter can be used for small resistive heating loads, some small appliances or hand tools, and incandescent lights (use DC whenever possible however). Modified sine wave inverters are appropriate for most loads including lights, electronic equipment, and most motors (in the last case the harmonics in the wave form will add to the dissipated power in the motor windings). Sine wave or simulate sine wave inverters can operate any load within their rated power range.

- Surge Overload Capacity and Protection. The chosen inverter should be able to exceed its rated capacity for a limited period of time (seconds). This feature is necessary for loads such as motors which may draw several times their rated wattage during startup. As a guideline, select an inverter which has a surge capacity at least three times the required operating watts. An automatic overload disconnect is recommended.

- Input Voltage. Select a unit which can handle the full input voltage which may be seen from the array or battery (series modules x the open circuit voltage per module, or 2.7 x the number of battery cells in series). A sensing circuit is useful to prevent damage. Generally the higher the load demand, the higher will be the selected nominal DC input voltage of the inverter.

- Frequency. 60 Hz in North America, 50 Hz in most other countries.

- Efficiency. Many inverter manufacturers claim high efficiency, exceeding 90%. However, this may apply only near the peak rated output. Look for a unit rated at high efficiency over a broad range of loads. Generally inverters using pulse width modulation can be expected to have the highest efficiencies.

- Duty Rating. This is the amount of time the unit can supply the maximum load. Exceeding this may cause failure. Thus the unit should be slightly oversized, and provide near constant efficiency over a range of loads.

- Power Factor. Specify a value near unity for best results.

- Modularity. This is only important if the system requires multiple units connected in parallel to service different loads.

DC-DC Converters:

DC-DC converters are used where it is necessary to convert from one DC voltage to another such as in some communication applications where different loads require different voltages. An alternative is to have a special module built to provide the non-system voltage, or to use a Maximum Power Point Tracker (MPPT). In an MPPT, the power from the array at its maximum power point is converted to another voltage where the load can use it more efficiently. One such application is in water pumping where the load varies as well as the solar insolation. In general:

- For applications requiring less than 1000 Watts, use a DC-DC converter.

- For applications greater than 1000 Watts, select a MPPT or other control feature where the photovoltaic modules are switched into different series and parallel configurations to achieve the required voltage.

11.4 Choosing Auxiliary Battery Chargers

Auxiliary battery chargers are used in hybrid systems to charge batteries using an engine generator. Be sure to select a battery charger specifically designed for use with diesel or gas gensets. Conventional deep cycle chargers are seldom appropriate.

Consider the maximum output of the generator versus the desired and practical battery charge acceptance capabilities.

11.5 Choosing a Back-up Diesel or Gas Generator

The selection of a diesel or gas driven generator set is based on a number of factors including application duty cycle, peak load in kW, power factor, voltage and phase, ambient conditions, limits of frequency variation and response to load transients, limits to voltage dip and recovery time, motor sizes and starting characteristics, and information regarding on-line load when large motors are started.

Power transfer devices are required to separate the diesel subsystem from any other system AC source (i.e. inverter, utility etc.) due to the "out of phase" nature of the system's multiple AC sources. Switching can be manual, semi-automatic or fully automatic, depending on how quickly the transfer must be made. Automatic operation represents a significant cost, but is required for critical emergency systems and hybrid power systems. If the diesel generator is only to be used intermittently, special features are required in the control system. Intermittent charge diesel systems complete with battery and controls are now available from Canadian manufacturers.

Factors to consider during selection of a backup system include location and space, floor loading, isolation of vibration, room ventilation, engine exhaust piping and insulation, noise control, engine cooling method, antifreeze protection, fuel storage, insurance, emission requirements and starting aids. Proper maintenance is essential, and the engine should be started at least once a week and operated under load. Repair information on all major components of the engine should be readily available.

11.6 Selecting Wire Types and Sizes

Selecting the correct size and type of wire for the system or different parts of the system will increase performance and reliability. In general the DC parts of the system will be low voltage. Voltage drops in the wires must be small in order to ensure that power at the correct voltage is delivered. For AC circuits, the voltage is higher, so larger voltage drops in the wires are more tolerable. In general use copper wires only and select wire sizes to ensure less than 2% - 5% voltage drop between components. Use Table 11.1 to select wiring types and size for minimum voltage drop in DC parts of the system.

TABLE 11.1

COPPER CONDUCTOR SIZES FOR 5% DROP IN VOLTAGE ON 6 V-TWO CONDUCTORS

Current	One Way Distance in Metres from Power Source Measured Along the Conductor Run Calculated for Conductor Temperature of 20°C				
Amperes	No.12 AWG	No. 10 AWG	No. 8 AWG	No. 6 AWG	No. 4 AWG
2 1/2	11.5	18.3	28.5	49.4	72.2
4 1/4	6.8	10.8	16.8	26.7	42.5
7	4.1	6.5	10.2	16.2	42.5
10	2.9	4.6	7.1	11.3	18.0
12	2.4	3.8	5.9	9.5	15.0
15	1.9	3.1	4.8	7.6	12.0
20	1.4	2.3	3.6	5.7	9.0

NOTE: *Acceptable one way distance in metres (L) for a selected wire size may be calculated using the following formula where one or all of the actual current (I), the actual voltage (V) and the actual voltage drop permitted (P) differ from Table D4 (in the Canadian Electrical Code, Part I):*

$$L = \frac{V}{6} \times \frac{P}{5} \times \frac{I_1}{I} \times L_1$$

where:

I_1 = *current shown in Table 11.1 closest to the actual current* (I)

L_1 = *one way distance in metres shown in Table 11.1 corresponding to the wire size used for the value* I_1 *selected.*

Example: System Characteristics:

$V = 12\ V$

$P = 7\%$

$I = 3A$

Wire size = No. 12 AWG

Values of I_1 *and* L_1 *to be used in the calculation are:*

$I_1 = 2.5\ A$

$L_1 = 11.5\ m$

$$L = \frac{12}{6} \times \frac{7}{5} \times \frac{2.5}{3} \times 11.5 = 26.8\ m$$

Source: Canadian Electrical Code, Part I

CHAPTER 12

ESTIMATING SYSTEM PERFORMANCE

This chapter describes how to estimate the annual performance of an actual photovoltaic system. The system will have been sized and specified in Chapters 10 and 11 to meet the highest-load/lowest solar input conditions. It is important to estimate what the actual performance of the system might be under typical conditions. This also allows any adjustment to be made in key component specifications.

12.1 Estimating Actual Losses in the System

Estimating losses in the system is an integral part of the design process. In the sizing worksheets, various losses were included as correction factors or efficiencies. Once all the components of the system are selected, a more accurate calculation of the actual losses is possible. If necessary, the designer can correct the design at this point in an iterative procedure. The proper procedure is as follows:

- Start from the load and work backwards towards the array.
- Treat the AC and DC components of the system separately.
- For the AC system calculate all the losses in the wires leading from the inverter to the loads. This may be done by finding the effective resistance of the wire from its length and its resistance (from standard resistance/1000 feet tables) and multiplying by current squared. Adding this loss to the actual load also gives a check on the required size of the inverter. When calculating wire lengths, be sure to use the entire conductor length, which is twice the distance between components in 2 conductor cable.
- Determine the efficiency of the inverter of the anticipated operating capacity from manufacturer's specifications.
- Now estimate the total power needed into the inverter (load plus wire losses between inverter and loads plus losses in inverter). Divide by the input DC voltage to determine the inverter input DC current. This current may now be used to calculate losses in the cables leading from the battery to the inverter (where battery storage is present), or between the array and the inverter in a direct drive system.
- For DC loads, the losses can be computed by working backwards in the same manner as for the AC system, except that there will be no inverter.
- For systems with both AC and DC loads, treat the two segments of the system separately, and sum the power requirements at the battery (or array for direct drive systems).
- For systems where battery storage is used, estimate the additional system losses in the selected battery system and battery charge controller, and the losses in the wires from the array to the battery bank. Note that battery voltage is typically 10% higher when charging than when discharging.

- For blocking diodes, the losses will be equivalent to the forward voltage of the diode multiplied by the current through the diode. For a single module with 2.5 Amperes of current, and a diode forward voltage of 0.3 Volt, the loss will be 0.75 Watt, or close to 2% for a 40 Watt peak module.

Use a System Losses Worksheet to estimate losses in wiring and components. An example is shown here and blank worksheets are given in Appendix II. Recheck the sizing procedures in Sizing Worksheets 1-6 to ensure that adequate allowance was made for system losses.

Points to consider when using the System Losses Worksheet include the following:

i) A photovoltaic system with batteries operates independently upstream and downstream of the batteries. Downstream, the current is determined by the load, upstream by the array output (insolation). The losses should be calculated separately for the two parts of the system.

ii) After completing the worksheet for "typical" values, calculate the overall system efficiency (LOAD - ARRAY OUTPUT), and then apply this factor to the average daily load to determine the average energy losses per day. Recheck the array size based on these losses.

iii) To ensure that all components are properly rated for the maximum demands (for fuse sizing, etc.), complete the worksheet again using maximum load and maximum array power to determine the maximum power that must be handled at each point in the system.

SYSTEM LOSSES WORKSHEET

			DC	AC
A	LOAD (watts)			
	Wiring: Inverter to Load:			
	Type			
B	Length (ft)			
C	Resistance (ohms/1000 ft)			
D	Voltage (volts)			
E	Current (amps)	A/D		
F	Loss (watts)	$B * C * E^2/1000$		
	Inverter:			
G	Output (watts)	A + F		
H	Efficiecy (%)			
I	Input Power (watts)	G/H		
	Wiring: Battery to Inverter or Load:			
	Type			
J	Length (ft)			
K	Resistance (ohms/1000 ft)			
L	Voltage (volts)			
M	Current (amps)	I/L or A/L		
N	Loss (watts)	$J * K * M^2/1000$		
	Battery & Charge Controller			
O	Total power delivered (watts)	(A+N)dc + (I+N)ac		
P	Efficiency (%)			
Q	Input power (watts)	O/P		
	Wiring: Array to Battery:			
	Type			
R	Length (ft)			
S	Resistance (ohms/1000 ft)			
T	Voltage (volts)			
U	Current (amps)	Q/T		
V	Loss (watts)	$R * S * U^2/1000$		
	Array:			
W	Blocking Diode Voltage Drop (volts)			
X	Blocking Diode loss (watts)	W * U		
Y	Total Power delivered	Q + V + X		

12.2 Performance Analysis Techniques

For a stand alone system with storage, the analysis should determine if there is power for the load at all times. In particular, it is necessary to check whether the autonomy of battery storage is sufficient.

For a system which operates over 12 months, the analysis would normally be on a monthly basis, starting, say, in April, with the battery fully charged. Knowing the average temperature and insolation (average peak hours/day), for that month, and assuming that the battery starts out fully charged, the designer can compute the total array output (Ampere-hours), the load usage (Ampere-hours) and hence the battery storage at the end of the month. One can then check on the number of autonomy days throughout the year to see if the design is satisfactory.

There must be a monthly adjustment to account for changes in ambient temperature as this affects both array and battery performance. A simplified approach is to assume that the temperature changes from the average temperature in one month to a new average temperature at the start of the next month (unless the battery is in a heated enclosure).

12.3 Monthly Performance Analysis Worksheet

12.3.1 Stand-Alone Systems

For a quick analysis of the performance of a stand alone system along the lines just discussed, use Performance Worksheet #1. This is designed for a month by month analysis of systems with or without battery storage, although it could also be used for other periods. It is also set up so that different loads can be specified in each period.

Use Performance Worksheet #1 for a system with battery storage as follows:

- Select the starting month and record the average ambient temperature, days in month, average insolation, load in Ampere-Hours per day, and battery storage at the start of the month (corrected to the average temperature for that month using the battery derating factor from Sizing Worksheet #2 -- Chapter 10).

- Compute the power used by the load, (including system losses), and the total array output for the period, and hence the battery storage at the end of the month. If the array supplies more energy than used by the load, then the battery storage entered at the end of the month will be incremented by that amount up to the maximum storage capacity of the battery. The autonomy days can be checked at this time to ensure that the design specifications are met.

- For the start of the next month, enter all the relevant information in the first columns. For the battery storage at the start of the month, find a new battery derating factor and multiply the battery storage at the end of the previous month by the ratio of the new battery derating factor to the previous month's battery derating factor. Then proceed as for the previous month.

- Continue until the performance has been computed for the complete period of use. If the system has been properly designed, the computations will confirm that the system will operate properly, and give the buyer confidence in the system.

For stand-alone systems without storage, ignore battery storage and merely check that the array will supply power for the required number of hours in the usage period.

For stand alone systems without storage, the systems will have been sized to work well during peak (mid-day) insolation conditions. The energy supplied by the system is calculated from the peak output power, times the houses of operation, times a correction factor to allow for reduced efficiency when the system is operating at off-peak insolation values.

For example with a pump operating at approximately constant head, such as a groundwater pumping system, the long term average volume of water pumped is found by multiplying the peak hourly flow volume by the equivalent number of hours of peak sunshine for the month (from Worksheet No. 1), times an off-peak factor. A factor of about 0.6 applies to pumping systems with positive displacement pumps, and well-matched centrifugal pumps. Use of other kinds of pumps, or situations with unusually high incidences of haze in the atmosphere will require smaller factors to be used.

For the pumping system described on page 10.5 for example, the peak (midday) flow rate is 3 cubic meters per hour. During a month such as September, with 4.9 equivalent hours per day of peak sunshine, the average volume of water pumped per day is:

$$3 \times 4.9 \times 0.6 = 8.8 \text{ m3}$$

PERFORMANCE WORKSHEET #1: MONTHLY ANALYSIS OF SYSTEM WITH STORAGE

ARRAY SIZE 1800 WATTS ARRAY CURRENT 150 AMPS BATTERY SIZE 8000 AH

	A	B	C	D[1]	E[2]	F[3]	G	H	I	J
MONTH	AVERAGE TEMP. (degrees C)	AVERAGE INSOLATION (Peak Hrs.)	ARRAY OUTPUT (AH/DAY)	AVERAGE LOAD (AH/DAY)	BATTERY DERATING FACTOR	BATTERY STORAGE START OF MONTH (AH)	NET POWER USED (AH)	BATTERY STORAGE END OF MONTH (AH)	RESERVE CAPACITY (DAYS)	DESIGN SATISFIED (YES/NO)
						E*(H/E Previous)	DAYS in month x (C - D)	Lowest of F or F - G + C	H/D	
APR	3.2	4.3	645	300	0.85	6800	(10,350)	6800	22.5	YES
MAY	10.1	4.4	660	300	0.90	7200	(11,160)	7200	24	YES
JUN	14.1	4.1	615	300	0.92	7360	(9,450)	7360	24.5	YES
JUL	15.8	4.7	705	300	0.93	7440	(15,624)	7440	25	YES
AUG	14.8	4.4	660	300	0.92	7360	(11,160)	7360	24.5	YES
SEP	9.8	3.4	510	300	0.90	7200	(6,300)	7200	24	YES
OCT	4.7	2.6	390	300	0.86	6880	(2,790)	6880	23	YES
NOV	-5.5	1.7	255	300	0.82	6560	1,350	5210	17	YES
DEC	-13.1	1.6	240	300	0.78	4955	1,860	3095	10	NO
JAN	-16.5	1.5	225	300	0.72	1717	2,325	0	0	NO
FEB	-11.4	2.4	360	300	0.76	0	(1,680)	1680	6	NO
MAR	-6.7	3.5	525	300	0.80	1768	(6,975)	6400	21	YES

Notes:

1. Load including system losses
2. Battery Derating Factor from Sizing Worksheet #3 at monthly temperature and charging rate
3. Battery Storage at start of first month equals nominal capacity times E.
   Thereafter Battery Storage at start of month equals Battery Storage at end of previous month times ratio of current and previous derating factors.

12.3.2 Hybrid Systems:

For hybrid systems, use Performance Worksheet #2. This worksheet can be used to estimate the average period that the photovoltaic and diesel systems provide power each month, the operating costs of the system, use of fuel, diesel maintenance schedule, and a check on the basic design.

To use Performance Worksheet #2 proceed as follows:

* Find the difference between array output per day and daily load use for each month. If the load uses more power than provided by the array in a given month, then divide the derated battery capacity by the difference between load and array power. This gives the number of hours where the photovoltaic array and battery provides the power between cycles of generator use. If the array provides more power than the load, assume that the generator runs a nominal once every 10 days to keep it in running order.

* Assume the generator will be charging for the number of hours selected in the sizing procedure (e.g. 4 hours). Calculate the number of cycles per month by dividing the total hours per month by the sum of photovoltaic hours plus generator charging hours.

* Calculate the fractional photovoltaic and diesel contribution per month.

* Repeat for any other months of interest.

PERFORMANCE WORKSHEET #2: MONTHLY ANALYSIS OF HYBRID SYSTEM

ARRAY SIZE 2880 WATTS ARRAY CURRENT 60 AMPS BATTERY SIZE 500 AH ENGINE SIZE 4 K WATTS

	A	B	C	D[1]	E[2]	F[3]	G[4]	H[5]	I	J	K
MONTH	AVERAGE TEMP. (degrees C)	AVERAGE INSOLATION (Peak Hrs.)	ARRAY OUTPUT (AH/DAY)	AVERAGE LOAD (AH/DAY)	BATTERY DERATING FACTOR	CHARGE PER CYCLE (AH)	PV CYCLE TIME (DAYS)	TOTAL CYCLE TIME (DAYS)	NUMBER OF CYCLES IN MONTH	DEISEL FRACTION	PV FRACTION
						Nom *0.6/E	F/(D-C)	G + 0.17	Days/H	I*F/(D*Days)	1 - J
APR	3.2	4.5	270	300	0.9	330	11.0	11.2	3	0.11	0.89
MAY	10.1	5.2	312	300	0.9	330			3	0.11	0.89
JUN	14.1	5.1	306	300	0.9	330			3	0.11	0.89
JUL	15.8	5.7	342	300	0.9	330			3	0.11	0.89
AUG	14.8	5.2	312	300	0.9	330			3	0.11	0.89
SEP	9.8	4.9	294	300	0.9	330	55.0	55.2	3	0.11	0.89
OCT	4.7	3.0	180	300	0.9	330	2.8	3.0	10	0.35	0.65
NOV	-5.5	1.8	108	300	0.9	330	1.7	1.9	16	0.59	0.41
DEC	-13.1	1.3	78	300	0.9	330	1.5	1.7	18	0.64	0.36
JAN	-16.5	1.5	90	300	0.9	330	1.6	1.8	17	0.60	0.40
FEB	-11.4	2.7	162	300	0.9	330	2.4	2.6	11	0.43	0.57
MAR	-6.7	3.7	222	300	0.9	330	4.2	4.4	7	0.25	0.75

Notes:
1. Load including system losses
2. Battery Derating Factor from Sizing Worksheet #3 at monthly temperature and charging rate
3. Charge per cycle assumes battery is charged from 20% to 80% i.e. nominal size times 0.6 divided by the Battery Derating Factor
4. If Array Output is greater than Load (C>D), assume that diesel is turned on every 10 days for 4 hours (0.17 days) - minimum 3 cycles per month
5. Assuming diesel recharges the battery in 4 hours

12.4 Optimizing the Design

Using the worksheets discussed in the last section will indicate how the system rates technically. They also will provide a check on whether or not the storage capacity in terms of autonomous days is sufficient. The next step is to optimize the system economically, trying to "trim" any overdesign resulting from the sizing and specification procedures to obtain minimum cost. The sizing procedures tend to be conservative-assuming that battery storage is necessary to cover periods when there is no insolation and "rounding up" when selecting components. The best design is one where there is an optimum balance between performance and cost.

For the hybrid system, there is no unique solution to the design for a particular site. Again economics and performance must be in balance. A good design would be one in which there is at least a 30% saving on fuel and maintenance costs for the diesel generator, and the system pays for itself in a period less than 5 years. The designer would have to compute the capital costs of the installed system, the fuel used and its costs delivered and stored on site, and the maintenance costs for the hybrid system; then compare these to the costs for a diesel generator alone (or a generator-battery system alone). Only then can the system be rated. Such a calculation should be done before the designer commits to installing a hybrid system. It may be more economic to install a diesel generator-battery system alone.

Chapter 13 provides a life cycle costing technique that can be used to compare different photovoltaic systems or compare them with conventional power sources.

CHAPTER 13

LIFE CYCLE COSTING

13.1 Why Life Cycle Costing?

The technique of life cycle costing breaks out the cost of installing, operating and replacing each component of a system and also takes account of the time value of money. It can, therefore, be used to compare one photovoltaic system with another or to compare photovoltaic with conventional power sources. This will help the designer choose the most cost-effective power source for a given application.

The Life Cycle Cost of a system is the sum of the following costs:

Life Cycle = Capital + Maintenance + Energy + Replacement - Salvage

- Capital Cost of the system includes design, engineering, capital equipment, and installation costs. The Capital cost can be a lump sum or a series of principal and interest payments over the life of the system.

- Maintenance Cost for the system, is the sum of all yearly scheduled maintenance and operating costs, including operators fees, inspections, insurance, taxes, small part replacement, etc.

- Energy Cost for the system, is the sum of all yearly purchases of fuel used by the system. This will be zero for non-hybrid photovoltaic systems.

- Replacement Cost is the cost of replacing components over the life of the system. This is normally the sum of lump sums paid for replacement of components such as batteries during the life of the system.

- Salvage Value is the net value of the system at the end of its useful life. It, of course, is a "negative cost".

Because the above costs will occur in different years, it is necessary to convert these future costs into present-day equivalents or "present worth". This is done using an assumed "discount rate" which is a measure of the rate of return expected by an investor, adjusted for inflation. For example, if an investor expects a 10% per annum rate of return and the annual inflation rate over the life of the system is expected to be 4%, a discount rate of 6% per annum should be used.

To convert future costs to their present worth, multiply them by the Present Worth Factor, a factor based on an assumed discount rate and number of years. Two types of Present Worth Factor (PWF) can be used -- A Single PWF to convert a single payment in a particular year such as replacement (or salvage value), and a Uniform PWF to convert a recurring annual cost from the present to the particular year. Single and Uniform PWFs are given in Appendix III for discount rates up to 12% and periods up to 75 years.

Appendix III also contains a table of yearly principal and interest at different rates.

13.2 Example of Life Cycle Costing - Comparison of a Photovoltaic with a Diesel Generator System

Table 13.1 shows how a typical photovoltaic system with battery storage might be compared with a small diesel generator system on a life cycle basis. Values given are examples only.

TABLE 13.1
LIFE CYCLE COSTING EXAMPLE

ECONOMIC PARAMETERS:

System Life = 20 years
Loan Interest Rate = 10%
Investment Rate = 10%
Inflation Rate = 5%
Fuel Inflation Rate = 8%
Net Discount Rate = 5% (Investment Rate - Inflation Rate)
Net Fuel Discount Rate = 2% (Investment Rate - Fuel Inflation Rate)

BASIC COSTS:[1]

	PHOTOVOLTAIC SYSTEM	GENERATOR SYSTEM
Array (Watts)	500	-
Battery (Ahr)	750	-
Generator (Watts)	-	5,000
Cost	$12,000	$8,000
Salvage (20%)	($2,400)	($1,600)
Annual Maintenance Cost	$ 50	$ 300
Annual Fuel Cost	$ 0	$ 200
Battery Replacement Cost	$ 1,000	-
Engine Rebuild Cost	-	$ 500
PRESENT WORTH:[2]		
Capital (20 yearly payments)[3]	$17,319	$11,538
Maintenance Costs[4]	620	3,738
Energy Costs[5]	-	3,270
Replacement Rebuild Costs[6]		
. Battery Replacement at 10 years	610	-
. Engine Rebuild every 5 years	-	940
Salvage Value[7]	($900)	($600)
TOTAL LIFE CYCLE COST	**$17,649**	**$18,886**

Notes:

1. *Costs in Current Dollars of individual components of the system*
2. *Present Value of individual costs over life of the two systems*
3. *20 annual payments of principal and 10% interest at a net discount rate of 5%*
4. *20 annual payments for maintenance at a net discount rate of 5% (Uniform PWF)*
5. *20 annual payments for fuel at a net discount rate of 2% (Uniform PWF)*
6. *Single payments for replacements at a net discount rate of 5% (Single PWF)*
7. *Single receipt for salvage at end of 20 years at net discount rate of 5% (Single PWF)*

CHAPTER 14

INSTALLATION, TESTING AND COMMISSIONING

A stand-alone PV system will operate reliably provided it is properly sized, well-engineered, and properly installed. Since the cost of support structures and installation may be 25-40% of the total system cost, attention must be paid to proper design and installation. Everything possible should be done in advance to prepare the equipment for installation, and the logistics should be kept as simple as possible. This includes doing as much prefabrication and pre-wiring of sub-arrays, support structures, and other components in the factory as possible. Remember that all installation work should be compatible with a 20 to 30 year life expectancy.

The following guidelines should be followed during system installation, testing and commissioning. For more details, check manufacturer's instructions.

14.1 Preparing the Site

- Choose a location as close to the point of use as possible to avoid long wire runs.
- Re-check that the array will not be shaded between 9:00 a.m. and 3:00 p.m. on the shortest day of year, thereby reducing output. Remove whatever obstacles are present in the south-facing direction, so that the sun has full access.
- For pad mounted systems, prepare level site and pour reinforced concrete pad, or sink sonotubes at points of support. Embed anchor bolts in concrete. (See Sidebar for more on foundations.)
- Where wires are to be underground, prepare trenches and run conduit with cable or clad cable.
- Prepare a site for the battery enclosure. A desirable approach is to mount batteries in insulated enclosure sunk into the ground to avoid exposing batteries to extremes in temperature.

Sidebar: Array Support Foundations

An array foundation is designed to prevent it from sinking or uprooting during inclement weather, and to maintain proper array orientation with respect to the sun. A number of factors influence the selection of foundation, including site accessibility, local topography, soil properties, local building codes and availability of labour. A slab type foundation requires flat terrain and a large mass of concrete, so it is not suited to remote sites where the cost of transporting cement is high. Rugged terrain would also necessitate site excavation before placing the foundation. A block type foundation is better suited for remote locations and rugged terrain because little excavation is required and the blocks can be aligned easily, thereby facilitating the positioning of the blocks. A grade beam foundation is a compromise of the previous two systems, and is well suited for rolling terrain because the alignment between adjacent arrays is easy.

The ability of a foundation to resist vertical motion depends on the weight of the structure and on the strength of the soil, while the resistance to horizontal motion is directly related to soil properties. An engineering soil analysis should be conducted on site to determine soil density, cohesiveness and soil aggregate, all of which will dictate foundation weight and design.

End of Sidebar

14.2 Installing the Array

- The array should be installed facing within 15° of true south. Locate south using one of the following methods:

  (a) Use a compass. Then correct for the difference between true and magnetic north using isoclinical maps found in navigation reference manuals.

  (b) Observe the shadow cast by a vertical rod at a time halfway between sunrise and sunset. The shadow will be the north-south line.

  (c) Observe the shadow cast by a vertical rod near noon. The shortest shadow will indicate the true N-S line.

- Where several array rows are used, select the row to row spacing to minimize shading (See Sidebar).

- Install support structures for the modules at the pre-designed tilt angle, using an angle indicator.

- Connect the modules one by one to the support frame.

- Use stainless steel bolts whenever possible to avoid corrosion. Mount modules as per manufacturers instructions.

- Cover modules with black material such as plastic or canvas during interconnection. Never leave surface exposed during sunlit day when working on the wiring.

- Interconnect the arrays, working from the lowest towards the highest voltage position. Connect in small groups to avoid high voltages until the final connections.

Sidebar: Array Row Shading

Use the following method to estimate the minimum row spacing to prevent shading of one row by another. The spacing will depend on latitude, array height and array tilt.

1. Use Figure 14.1 to determine the ratio of height to inter-row spacing at the site latitude.
2. Use Table 14.1 to determine the actual height of a tilted array row.
3. Multiply 1) by 2) to obtain the minimum distance between back of one row and front of another.

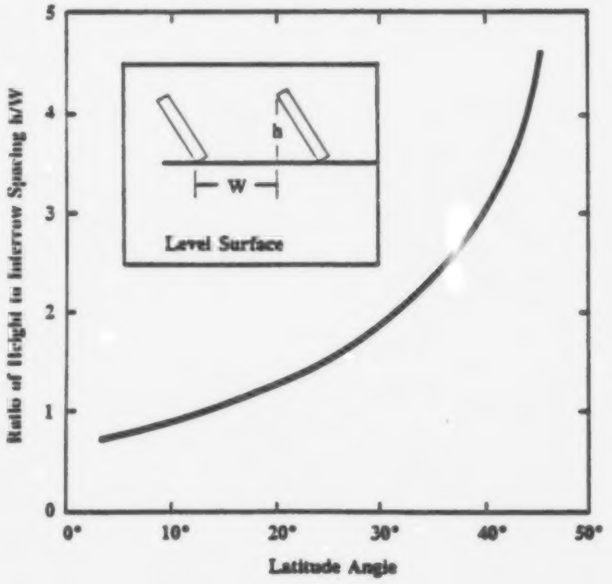


Figure 14.1: Height Spacing Ratio At Different Latitudes

TABLE 14.1

HEIGHT OF TILTED ARRAY IN METRES

	Number of modules		
Tilt Angle	**4**	**8**	**12**
15°	*0.3*	*0.7*	*1.03*
20°	*0.5*	*0.94*	*1.4*
25°	*0.6*	*1.2*	*1.7*
30°	*0.8*	*1.4*	*1.9*
35°	*0.87*	*1.6*	*2.3*
40°	*0.89*	*1.8*	*2.5*
45°	*1.1*	*1.9*	*2.8*
50°	*1.2*	*2.1*	*3.0*
55°	*1.25*	*2.3*	*3.3*
60°	*1.3*	*2.4*	*3.4*
65°	*1.4*	*2.5*	*3.6*
70°	*1.43*	*2.6*	*3.7*
75°	*1.5*	*2.7*	*3.8*

End of Sidebar

14.3 Installing the Batteries

- If a buried battery enclosure is used, select a well drained location and provide a drainhole in the battery enclosure.
- Provide adequate venting.
- Install the batteries as close to the array as possible to avoid long wire runs.

14.4 Installing Power Conditioning and Control System Components

- All electronic equipment must be protected from the environment if long life is to be attained.
- Where exposure to dust and dampness is possible, use conformal coatings on PC boards to protect electronics.
- Use CSA certified electrical service boxes.
- Pre-wire control/distribution boxes as much as possible.
- Provide adequate air circulation, particularly for inverters or shunt-type controllers which generate heat.
- Secure equipment in place with ready access provided for easy working.
- Do not install inverters in the same enclosure with batteries since switching the inverters could cause a spark and cause an explosion of gases generated by the battery. Moreover, gases could corrode electronic components.
- Install the inverter as close to batteries as possible, however, to decrease resistance losses due to high currents in wires (smaller wires can be used after inverter on AC side where output voltages are higher).
- Protect input and output of inverter with fuses. Provide disconnects on both DC and AC sides.
- Use metal oxide varistors (movistors) on input to controller (or inverter) to provide surge protection (See Figure 4.5).

14.5 Interconnecting the System

- Use proper size wires, anchor wires securely in position prior to interconnection. Use colour-coded wire -- **red** positive, **black** negative when using DC wire; **black** "line", **white** "neutral" when using AC wire.

- Pay careful attention to making good connections.

- Use connectors -- do not try to wrap bare wire around a terminal. Make sure connector size and wire size are compatible.

- Strip 3/8 inch to 1/2 inch of insulation from wires. Use crimp tool to attach connectors. Use ring type in preference to spade type.

- Solder the crimped connector, particularly in a marine environment.

- Make connections between sub-systems using terminal strips in weather resistant boxes (if outdoors).

- Make sure terminals and connectors are clean and of same type of metal. Tighten firmly. Do not use more than 2-3 connections to same terminal.

- Use proper wire for indoor and outdoor locations.

- When connecting the parts of the system, make sure modules are covered (to avoid shocks) and work from the lowest voltage towards the highest voltage.

  For typical PV system with battery and controller:

  1. Connect **load minus** to controller;
  2. Connect **battery minus** to controller;
  3. Connect **array minus** to controller;
  4. Connect **load plus** to controller;
  5. Connect **battery plus** to controller;
  6. Connect **array plus** to controller **and** then connect load to battery.

  For systems with no controller use same approach. Connect the negative leads first then the positive leads. The last connection should be the positive connection into the array.

- **Measure Array Performance Before Making the Last Connection by measuring insolation and no-load voltage (Voc) and current (Ioc).**

Sidebar: Cables, Conduits and Connectors

Standard DC practice should be followed in selecting cables, conduits and connectors for photovoltaic systems. Wiring is sized to minimize resistive power losses. The optimum size of wire will depend on the length of run, voltage drop, material cost, and the cost of the power produced by the PV system.

A photovoltaic system should be designed to accommodate changes in load by using busways which will accept plug-in devices and over-sized raceways. If the load is expected to increase in future, excess capacity should be added during installation.

The use of conduits can become a major cost factor if significant quantity is required. Other components of the system can substitute for dedicated conduit to save expense. When metal conduits are used to provide a system ground, the electrical continuity must be maintained, especially where joints are made.

Most photovoltaic systems use metal connections in junction boxes, similar to conventional wiring methods. Quick-connectors can be used to save labour, providing the metal contacts cannot be touched and are compatible with the inexpensive non-metallic sheathed cable that is used on many systems. Quick-connects should be waterproof and flexible enough to be installed in the field without special tools, and with gloves on in cold environments.

End of Sidebar

14.6 Protection and Grounding

- Install blocking diode between array and battery (if not included in controller).
- In a simple system install a manual disconnect switch between array and battery.
- Use fuses on either side of controller/inverter in highest voltage lead, not ground lead.
- Use movistor at input of inverter for surge protection. This shunts surge current to ground. A nearby lightning strike may destroy the movistor, but this may save the expensive inverter.
- Grounding -- provide low resistance path from a single point to earth ground. (Multiple grounding points can create "ground loop transients" which can disrupt the operation of electronic components.) Grounding is easily accomplished by using #6 AWG bare copper wire and copper plated rods driven into the earth. See Chapter 4 for more information on grounding.
- For larger systems, provide protection fence for public to prevent access and exposure for dangerous voltages and for currents.

Sidebar: Switchgear and Circuit Breakers

Switchgear in photovoltaic systems follows standard practice for DC systems. The power distribution subsystem is designed to serve as the electrical and physical interface between power source and load, in order to provide system overload and short-circuit protection as well as ensure manual circuit disconnect capability. Each separate load circuit should have a breaker or relay, and a main breaker should be provided for the input conductor current protection. In addition, the capability to manually disconnect the system is essential for safe maintenance.

The design of and components used in the power distribution subsystem must comply with existing codes and standards, as must junction boxes, circuit breakers, and AC and DC circuits. The controls may be switch-activated (usually manual), electromechanical (relays) or electronic (analog or digital microprocessors).

When a power conditioner is close coupled to a control system, electrical interference can cause a system malfunction. Automatic protection should shut down the unit when the controls detect high temperature, unbalanced operation in three-phase systems, over- or under-voltage, over current or the loss of synchronism. The system should not be re-started until a manual or automatic check-list has confirmed that all dangerous conditions have been rectified.

Many circuit breakers are limited in their DC interruption capability and, for 400 V DC service, it is necessary to use cubical type drawout breakers or series space 2 poles of a standard AC circuit breaker. Sectionalizing switches can be used for 'cold' switching, but they have neither a load break nor fault interruption capability. DC applications cannot utilize AC ground fault relays, but photovoltaic systems can accept hybrid industrial relays or non-contact hall effects sensors.

For DC fuses, 400 V units with special arc quenching characteristics are available. DC contactors can handle the requirements for loadbreak, sectionalizing and crowbarring, and the more expensive off-the-shelf models feature magnetic blowout and hold-in, as well as arc chutes.

Many control and protective devices are tested only to 250 VDC, and applications of higher voltage will need confirmation of suitability from the unit manufacturer.

End of Sidebar

14.7 Testing the System

Perform Mechanical Inspection.

- Check for ground faults. Make sure no exposed metal frames are live.
- Check array orientation. Use compass to verify that orientation is within 15° of true south. Check for objects which may cause shading.
- Check tilt angle using tilt indicator or level and protractor. Tilt angle should be within 5° of that specified by sizing calculations.
- Inspect all system hardware to verify that it is secure.
- Check all wiring to verify that it is neat, safe, well protected and meets any code requirements.
- Verify each connection to make sure each current path is correct.
- Verify that batteries, if any, are protected and well ventilated.

For an excellent reference document for photovoltaic system inspection see Section 690 of the United States National Electrical Code (NEC).

Measure Array Performance.

- Measure short circuit amperage using a shunt or clip-on ammeter. Short circuit amperage is directly proportional to insolation. Any discrepancy is normally due to incorrect array wiring. Measure solar insolation using pyranometer or reference device.
- Measure open circuit voltage. This varies with module temperature which may also be checked. If several modules are connected in parallel, the open circuit voltage observed may be slightly lower than expected because of module mismatch. This is not a matter of concern; the more important measurement is amperage. For large arrays (i.e. over 25 modules), check module temperature at a number of locations including the edge and centre of the array.
- Check for proper operation of controller. See manufacturers instructions for details.
- Check wire losses and for poor connections by measuring voltage, during normal operation, at array, controller, battery and load.
- It is always useful to measure charging and load amperage, using a clip-on ammeter, during normal system operation. Knowing insolation, module temperature, and operating voltage, an approximation of expected amperage can be made, and compared with observation.

Sidebar: Monitors, Alarms and Controls

The purpose of monitor and alarm functions are to alert the system operator as to the status of the system. No control action is taken by either device, although they may record the action of a control mechanism. Both monitor and alarm devices may be accessed either locally, or remotely (or both) via a suitable form of transmission. In general, an alarm device is either on or off, such as a low battery voltage indicating light or a generator on/off signal, whereas a monitor device can record or report a range of readings, such as a battery voltage or generator run-time.

At a minimum, a simple voltmeter is required to indicate battery state of charge and array operation. Other alarm or monitor devices may be added for the following:

- low voltage alarm
- array current meter
- module, ambient and battery temperature measurement.

The power conditioning unit usually incorporates many of these functions and also the control circuitry for the system. It controls load matching and voltage regulation, start-up and shut-down, over- and under-voltage shut-down, over-current shut-down, the disconnect in case a utility link is lost, (if applicable), voltage regulation, and frequency regulation.

For the monitoring of system performance, more elaborate sensors and data acquisition devices are required. These are described in Chapter 16.

End of Sidebar

14.8 Commissioning

- Once testing is completed and the system is operating, observe the performance of the system for a period of time to ensure it is working properly.
- A set of operational test readings should be made and recorded jointly with the owner/user representative for future performance comparison and assessment.
- Demonstrate operation of the system to the user.
- Provide training in operation and maintenance.
- Provide the user with detailed manuals on the system.
- Arrange for an acceptance certificate and warranty/service agreements.

Checklists are useful aids to installation, testing and commissioning.

CHAPTER 15

MAINTENANCE

15.1 The Importance of System Maintenance

A properly designed, installed and maintained photovoltaic system which uses quality components will provide many years of reliable service. Poor attention to maintenance can severely affect performance and component life. As an example, dust builds up on a module and may gradually reduce the output by 10-15%. Similarly, batteries will degrade in output over time. However, properly treated in the design and properly maintained (check on water line etc.) they will give the required storage for 10 years or more.

A good manual for the system will provide:

- operating instructions
- maintenance schedule
- troubleshooting procedures.

15.2 A Periodic Maintenance Schedule

It is important to establish a regular preventive maintenance schedule to ensure that the user has many years of trouble-free service. Establish a site log to record all maintenance scheduling and comments.

ARRAY

- Wash as needed
- Check Isc and Voc of individual array strings (use current shunt to measure current)
- Check wiring and connectors for cracking, rodent damage, fraying, etc.
- Check PV modules for cracked cells and glazing
- Check PV modules for encapsulant delamination and cell interconnect corrosion
- Check electrical leakage to ground

BATTERY

- Check electrolyte specific gravity (against nominal and expected value)
- Check electrolyte level
- Check for terminal corrosion
- Check cell or battery open circuit and load voltage measurements
- Check individual cell voltages

INSTRUMENTATION AND CONTROLS

- Check instrumentation calibration
- Exercise control elements
  - Voltage Limit controls
  - Auto trip circuit breakers
  - Sense/enable type controls

LOADS

- Follow manufacturer's recommendations
  - Lubrication
  - Motor brushes
  - Cleaning

GENERAL

- Follow safety procedures
- Review monitoring data regularly,
- Check fuses and load circuit breakers
- Compare measured load utilization to predicted values
- Compare measured array output to predicted values
- Check for lightning damage in PV system circuits and components
- Check for defective instrumentation

15.3 Troubleshooting and Fault Tracing

Prepare a system checklist and fault tracing procedure for persons servicing the system to follow. This should include probable cause, and corrective action. Table 15.1 provides a general guide to troubleshooting.

More detailed fault tracing and corrective action procedures are required for each potential problem. For example, if a small PV array is producing less than design power for a given insolation condition, the faulty module can be simply located by covering each individual module and noting the change in array output. The module can then be checked and repaired and replaced. In larger arrays, sequentially halve the array until the fault is located.

The following is an example of a fault tracing procedure for low battery voltage.

Fault Tracing Example

LOW BATTERY VOLTAGE (most common indicator of a problem)

Assuming that:

- the system has been properly sized
- no natural disasters have occurred, such as two weeks of darkness or one foot of snow on the array

1. Check the most obvious - is a periodic load on all the time?

   Yes - turn it off and hope the battery can be recharged
   No - mentally break the system into INPUT and OUTPUT components

A. Input

2. Check for incoming current to battery on a sunny day.

No Current	Current
check for current to regulator	cover array or wait for night to check for reverse current

No Current	Current	Reverse C.	No Reverse C.
go to array checklist	go to regulator checklist	check individual blocking diodes and replace faulty ones	go to 3

B. Output

3. check individual loads for excessive current -- usually not a problem since properly sized fuses should isolate battery from shorts, etc.

4. check battery itself - level and S.G. of electrolyte
   - voltage across individual cells
   (shorted individual cells is a common occurrence*)

* this is usually indicated by low overall voltage and excessive bubbling from all non-shorted cells when trying to charge the battery

TABLE 15.1

TROUBLESHOOTING CHECKLIST

Cause	Corrective Measure
Array	
1. Loose wires	Tighten
2. Improper wiring configuration	Reconfigure
3. Broken module	Replace
4. Shading	Remove obstruction or relocate array
5. Improper orientation	Re-orient
Wiring System	
1. Excessive voltage drop	Use heavier wire
2. High resistance connections	Clean and tighten
3. Short circuit	Repair
Controller	
1. Loose conn. at term. block	Tighten
2. High resistance at relay contacts	Replace control
3. Inoperative	Replace control
4. Relay fused shut	Replace control
5. Electrical interference	Remove source or filter
6. Loadshedding occurred	Wait for battery to charge
Load	
1. Failed	Replace. Check for improper voltage
2. Excessive current demand	Check system sizing Check load for failure
3. Check for generation of electrical noise	Install filter

CHAPTER 16

PERFORMANCE MONITORING

16.1 Introduction

Once the system is operating, it is important to assess its performance. Usually the main questions are how much solar energy is available, and how well the photovoltaic system lives up to its design performance.

With battery driven systems, the main performance issue is whether or not the batteries have sufficient autonomy. With battery driven systems using back-up from other power sources, the issue is usually whether or not the percentage of time the back-up power source needs to be operated is less than, or greater than, that originally promised in the design. With non-battery operated systems such as water pumps, the issue is whether the average daily volume of water pumped is greater than, or less than, that originally promised in the design.

16.2 Selection of Data to Monitor

The initial data that are required are the solar radiation for the period of monitoring. If a rough assessment of performance for a simple system is all that is required, and if the system is located in non-mountainous terrain, then it is usually possible to use data from Environment Canada (Atmospheric Environment Service) and to establish the amount of daily solar radiation from a nearby meterological station. Records on Solar Radiation and Bright Sunshine Hours for example are usually available within a few weeks of the end of the month in which they were gathered. If the closest station is a long distance from the system being monitored, or if the terrain is mountainous, then the solar radiation should be directly measured on-site using a pyranometer, or monitor panel (see below).

Stand-alone Systems with Battery Storage

With battery systems, an important issue is whether the batteries are operating correctly. Monitoring of the electric power entering and leaving the battery is carried out, so that the battery performance may be evaluated. With a simple system consisting of photovoltaic array, batteries and a load (see Figure 16.1), monitoring the solar radiation, the power (volts and amps) into the batteries and the power (volts and amps) out of the batteries enables the performance of the photovoltaic panels and the batteries to be evaluated.

Stand-alone Systems without Storage

In systems without battery storage, such as a water pumping system, it may be important to know how efficiently each of the subsystem components are operating. A simplified drawing of a pumping system is shown in Figure 16.2. Assessment of such a system, consisting of the photovoltaic panels, an interface (e.g. an inverter or a DC-DC converter), a motor and a pump involves measurements of electrical and mechanical energy at various points in the system. At a minimum, measure the water flow under stable sunny conditions at solar noon. These measurements enable the efficiencies of the photovoltaic array, the interface, the motor and the pump all to be determined. If a performance assessment of the whole system is required, then a check is made by measuring the overall system efficiency, using measurements of the solar radiation (power in) and the head and flow supplied by the pump (power out). The gross system efficiency is the ratio of the power out to the power in. Daily values of this ratio are usually reported.

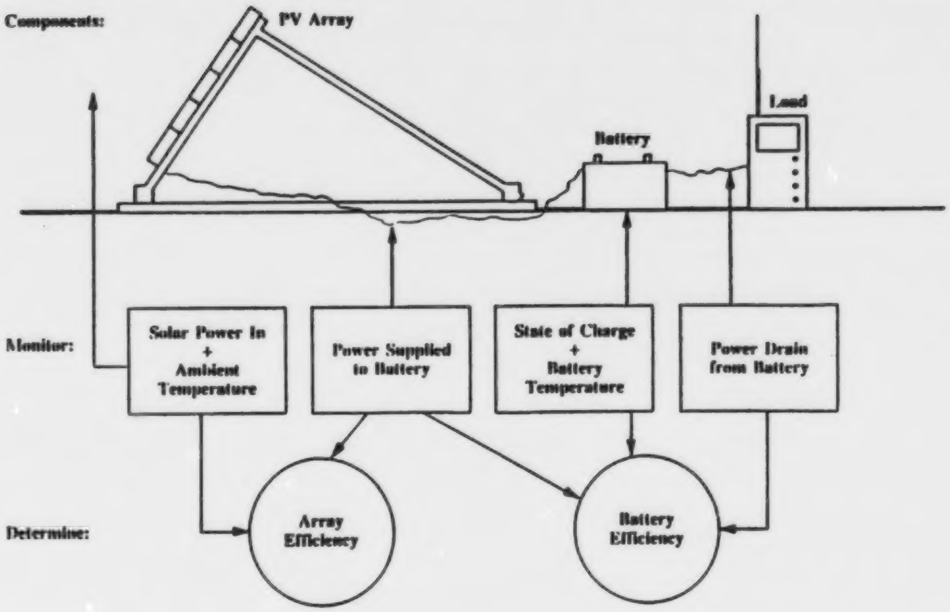

Components:
PV Array
Load
Battery
Monitor:
Solar Power In + Ambient Temperature
Power Supplied to Battery
State of Charge + Battery Temperature
Power Drain from Battery
Determine:
Array Efficiency
Battery Efficiency

Figure 16.1: Monitoring a Photovoltaic System With Battery Storage

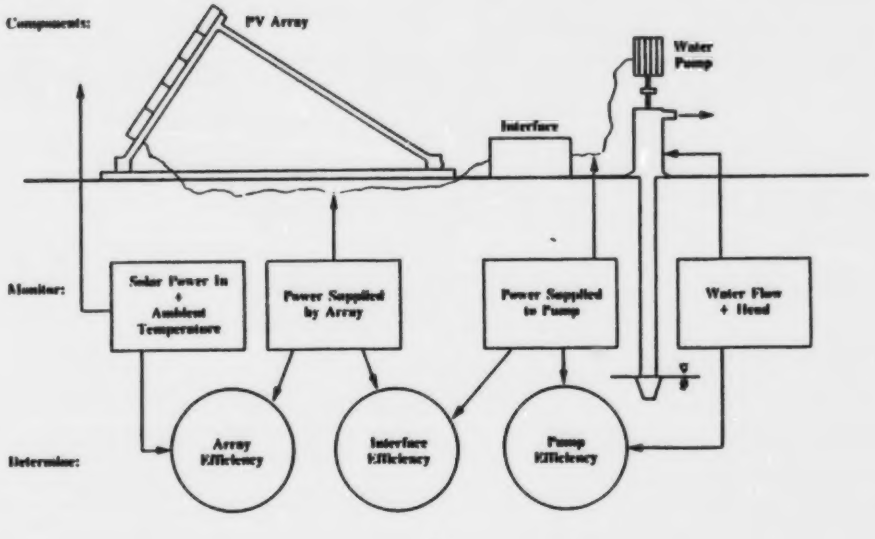

Components:
PV Array
Water Pump
Interface
Monitor:
Solar Power In + Ambient Temperature
Power Supplied by Array
Power Supplied to Pump
Water Flow + Head
Determine:
Array Efficiency
Interface Efficiency
Pump Efficiency

Figure 16.2: Monitoring a Photovoltaic System Without Storage

Hybrid Systems:

In a PV/diesel hybrid system (with battery storage), the key to a successful system is to reduce the operating costs, which are primarily a function of the run time of the diesel engine. Therefore, the key parameter to monitor is the total run time of the diesel. Other parameters of interest are the number of start/stop cycles (to determine if the engine is experiencing too many short runs, which tend to increase the required maintenance), and the total fuel consumption (which, in combination with the run time, can be used to determine the average efficiency of the genset). As with all battery based power systems, the battery state of charge (from terminal voltage measurement) is the simplest method of determining if power is available. If more detailed monitoring is in use, a record of the battery terminal voltage at which the generator is started and stopped could be used to determine if the system is operating up to specifications. Other parameters which are normally monitored in a PV only system (insolation, temperatures, etc.) should also be monitored.

16.3 Monitoring System

The monitoring system may be quite crude for a simple system. If solar radiation data from a nearby station are available, and if the power requirements for the load are known, then it is possible to assess the performance of the whole system by making periodic (e.g. daily) manual measurements of the battery voltage.

For more complicated systems, and for systems where the solar radiation needs to be measured, a data logger should be set up. Several Canadian and foreign made systems, are available and most systems are able to accept data from several channels. The data logger should have its own batteries, and should not rely on the batteries of the system being monitored. The data logger should be programmed to make spot readings of solar radiation at frequent intervals during the day, and the results totalled to determine the daily energy input. A frequency of one reading every 5 minutes is satisfactory, but more frequent measurements are preferable. Readings at less frequent intervals give an inaccurate assessment of the daily energy input. Integrated values over longer time periods can be used for summary analysis. The sensor for solar radiation may be a pyranometer set at the same angle to the sun as the photovoltaic array, or it may be a small calibrated photovoltaic panel with arrangements to measure the current through a shunt wired across the panel.

Electrical parameters such as battery voltages may be measured directly. Battery input and output currents may be measured indirectly by using shunts of the correct resistance. For systems which use photovoltaic panels to drive electric motors such as water pumping systems, the speed and mechanical torque supplied by the motor may be found indirectly. For example, for DC permanent magnet motors, the speed may be found directly from the applied voltage, and the torque may be found from the current. The final water power delivered is found by measuring the flow of water using a water meter fitted with a counter switch, which opens and closes every time a given small volume of water passes. This counter switch is connected to one channel of the datalogger. The head on the pump is found from the difference in elevation between the groundwater table and the water surface elevation at the highest point (usually the water reservoir), plus the head losses in the pipe. The head is required in the calculation of final delivered power, but the head remains approximately constant in most small flow applications and therefore need not be measured by the datalogger. Weekly or monthly manual measurements of head are adequate.

16.4 Analysis of Data

Most dataloggers are capable of measuring and storing data from at least 6 or 7 channels at a rate of one reading on each channel every 30 seconds to 5 minutes for periods of at least 2 to 3 months. This results in a large amount of data for which computer processing is essential.

Data is downloaded either directly from the datalogger or from intermediary storage such as a cassette tape into a desktop computer, such as an IBM PC. Alternatively, a microcomputer can be used on site to both act as a datalogger, and analyze the data collected.

Daily average information is usually the main basis for performance assessment, so daily averages of readings for all channels are computed first. This may be carried out using software supplied by the manufacturer of the datalogger, or by loading the data onto a computer spreadsheet. Calibration constants, for example the bias and slope values for determining the level of insolation from field readings, must be included for each channel. These are derived when the datalogger is first set up in the field, or after the data has been gathered and stored in the computer. The use of a spreadsheet format also helps with the deviation of other results such as calculation of long term averages and efficiencies, and in tabulations, graphing and report preparation.

APPENDIX I

SOLAR INSOLATION DATA

LOCATIONS WHERE SOLAR RADIATION IS MEASURED ON TILTED SURFACES IN CANADA:

BRITISH COLUMBIA:

Abbotsford A
Cape St. James
Castelgar A
Comox
Fort Nelson A
Fort St. John
Kamloops A
Penticton A
Port Hardy A
*Prince George A
Prince Rupert A
Quesnel A

Sandspit A
Smithers A
Spring Island
Summerland CDA
Terrace A
Tofino A
*Vancouver UBC
Victoria Int'l A
Williams Lake A

ALBERTA:

Calgary Int'l A
Cold Lake A
Coronation
*Edmonton Int'l A
Fort McMurray A
Grande Prairie A

Lethbridge A
Medicine Hat A
Peace River A
Red Deer A
Rocky Mtn. House
Vermilion A
Whitecourt

SASKATCHEWAN:

Broadview
Estevan A
Moose Jaw A
North Battleford A
Prince Albert A
*Regina A

Saskatoon
Swift Current CDA
Uranium City A
Wynyard
Yorkton A

MANITOBA:

Brandon A
Churchill A
Dauphin A
Portage la Prairie A

The Pas A
Thompson A
*Winnipeg Int'l A

ONTARIO:

Atikokan
Big Trout Lake
Earlton
Geraldton
Gore Bay A
Kapuskasing A
Kenora A
Kingston A
London A
Mount Forest
Muskoka A
North Bay A
Ottawa NRC
*Sault Ste. Marie A
Simcoe
Sioux Lookout A
Sudbury A
Thunder Bay A
Timmins A
*Toronto A
Trenton A
Wiarton A
Windsor A

QUEBEC:

Bagotville A
Baie-Comeau A
Fort-Chimo A
Grindstone Island
Lake Eon A
Monte Joli A
*Montreal Jean Brebeuf
Nitchequon
Poste-de-la-Baleine
Quebec A
*Riviere-du-Loup
Roberval A
Ste-Agathe-des-Monts
St-Hubert A
Schefferville A
Sept-Iles UA
Sherbrooke A
Val-d'Or

NEW BRUNSWICK:

Charlo A
Chatham A
*Fredericton CDA
Moncton A
Saint-John A

NOVA SCOTIA:

Greenwood A
Sable Island
Shearwater
Sydney A
*Truro
Yarmouth A

PRINCE EDWARD ISLAND:

*Charlottetown CDA
Summerside A

NEWFOUNDLAND:

- Battle harbour
- Bonavista
- Cartwright
- Daniels Harbour
- Deer Lake A
- Gander Int'l A
- Goose UA
- Hopedale
- *St. John's A
- Stephenville A
- Wabush Lake A

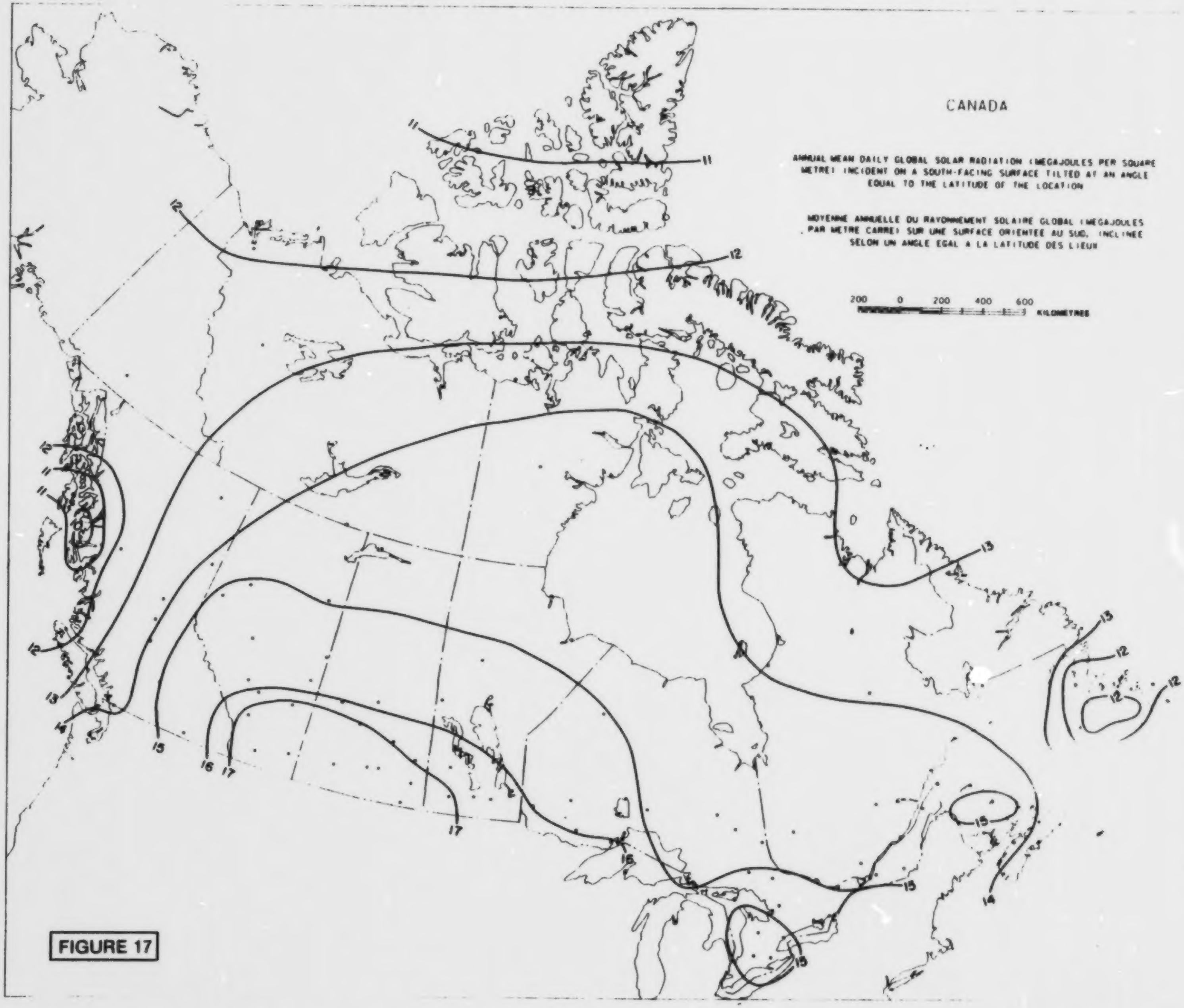
NORTHWEST TERRITORIES:

- Alert
- Baker Lake
- Cambridge Bay A
- Coral Harbour A
- Fort Smith A
- *Frobisher Bay A
- Hall Beach A
- Inuvik UA
- Mould Bay
- Norman Wells A
- Resolute A

YUKON:

- *Whitehorse A

* Example Tables Attached



CANADA

ANNUAL MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION

MOYENNE ANNUELLE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

200 0 200 400 600 KILOMETRES
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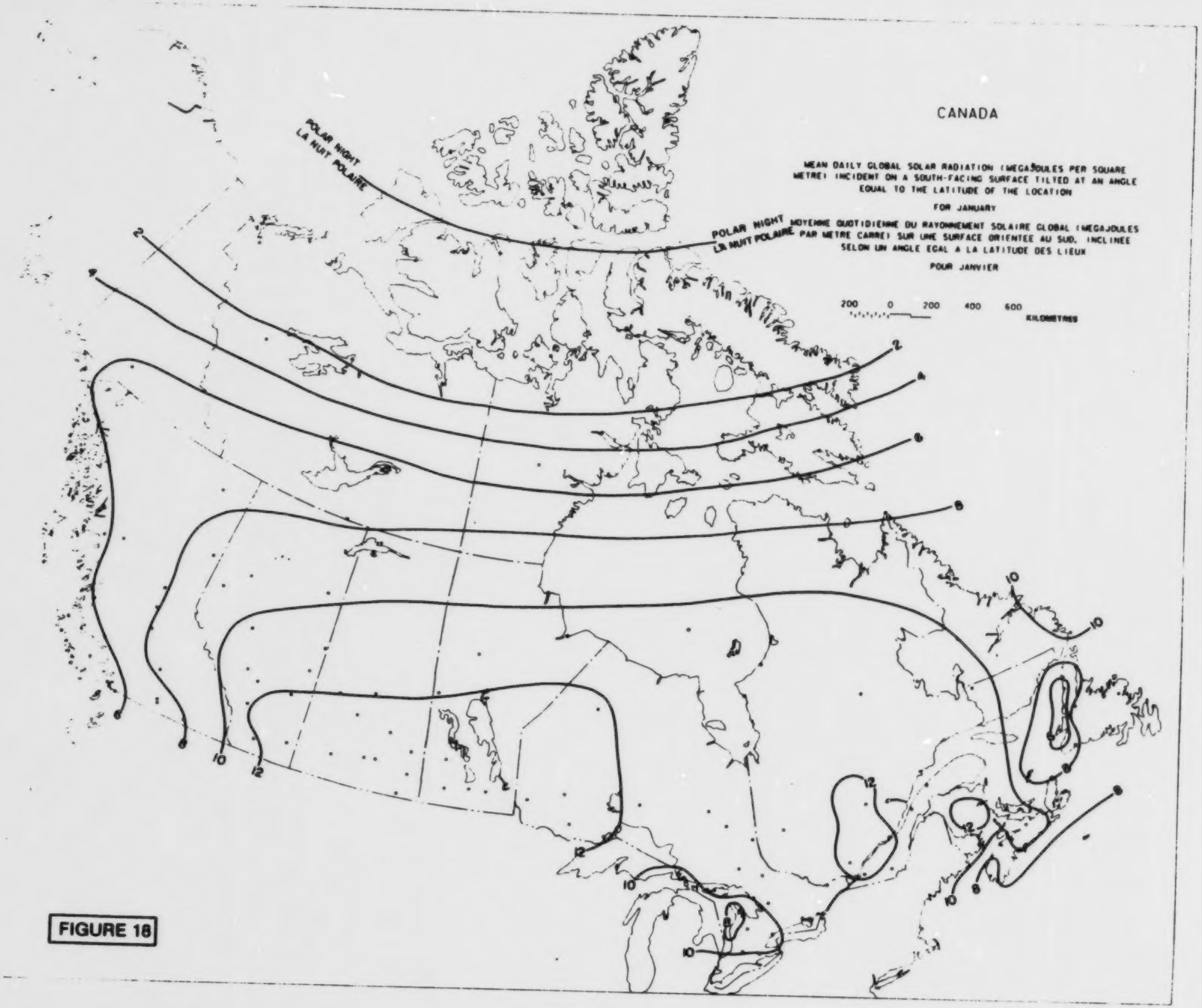
FIGURE 17



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION

FOR JANUARY

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

POUR JANVIER

POLAR NIGHT
LA NUIT POLAIRE
POLAR NIGHT
LA NUIT POLAIRE
200 0 200 400 600
KILOMETRES
2
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FIGURE 18

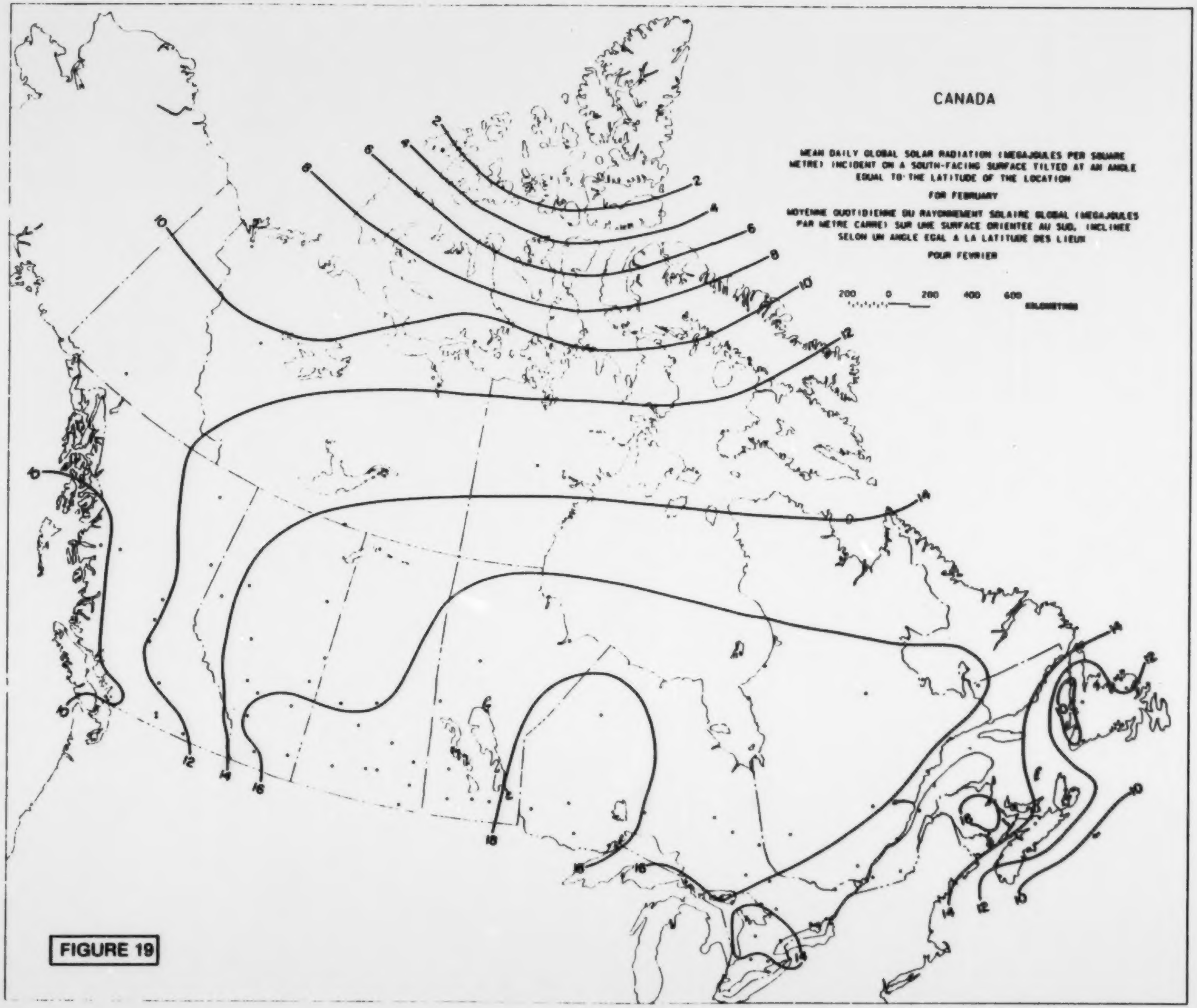

FIGURE 19

CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION

FOR FEBRUARY

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

POUR FEVRIER

200 0 200 400 600
KILOMETRES
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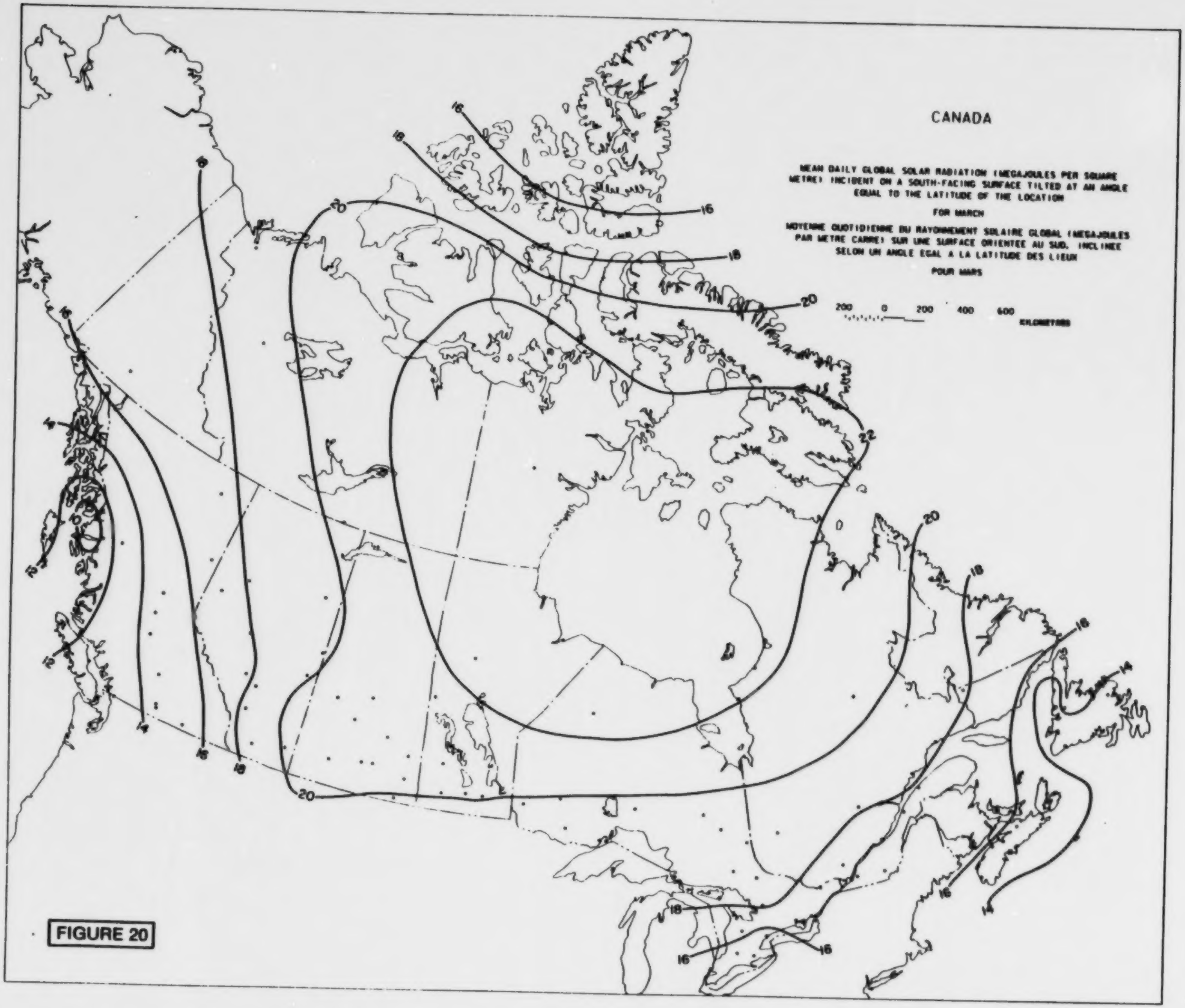

16
18
20
22
14
12
200 0 200 400 600
KILOMETRES

CANADA

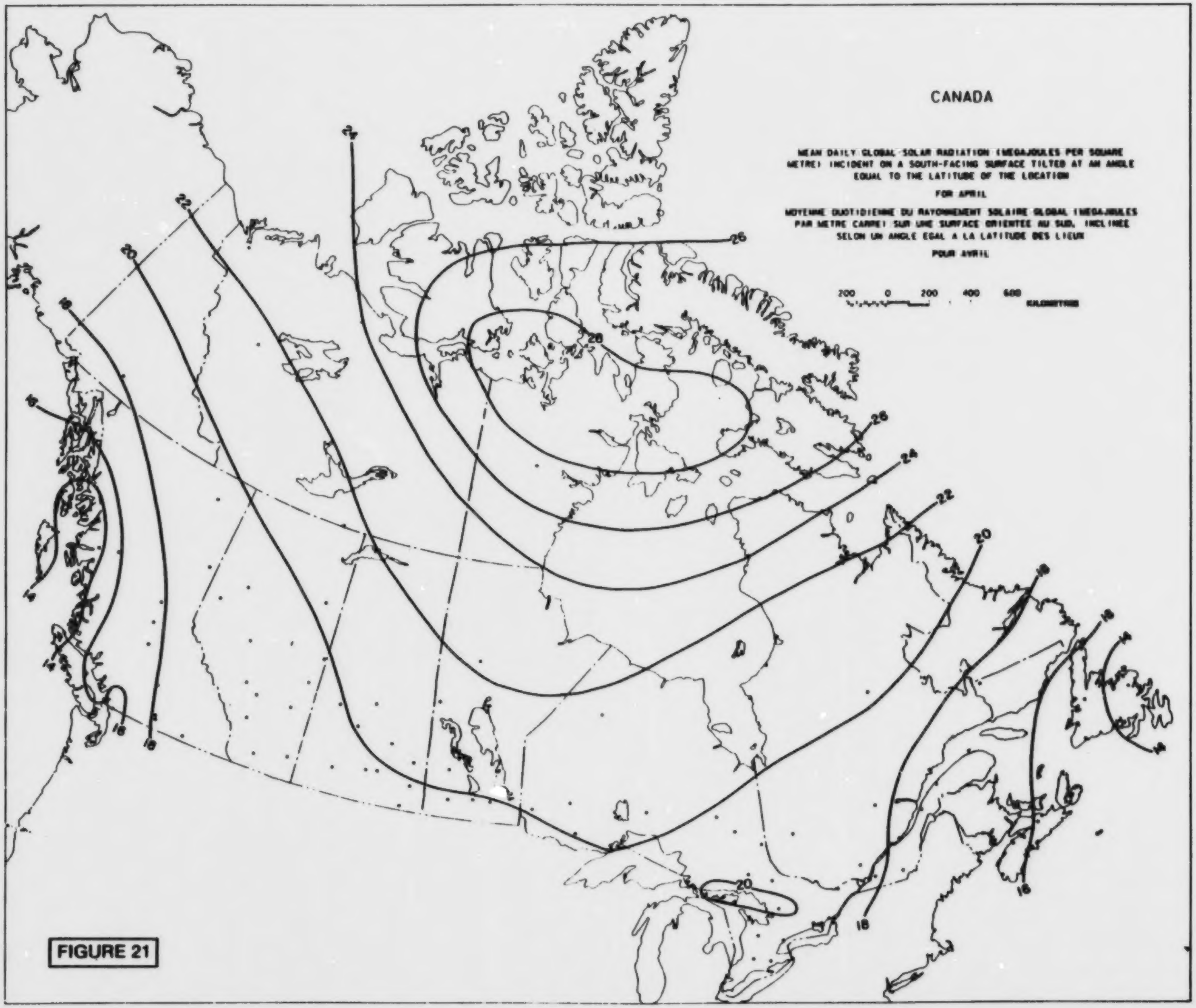
MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION

FOR MARCH

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

POUR MARS

FIGURE 20



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION

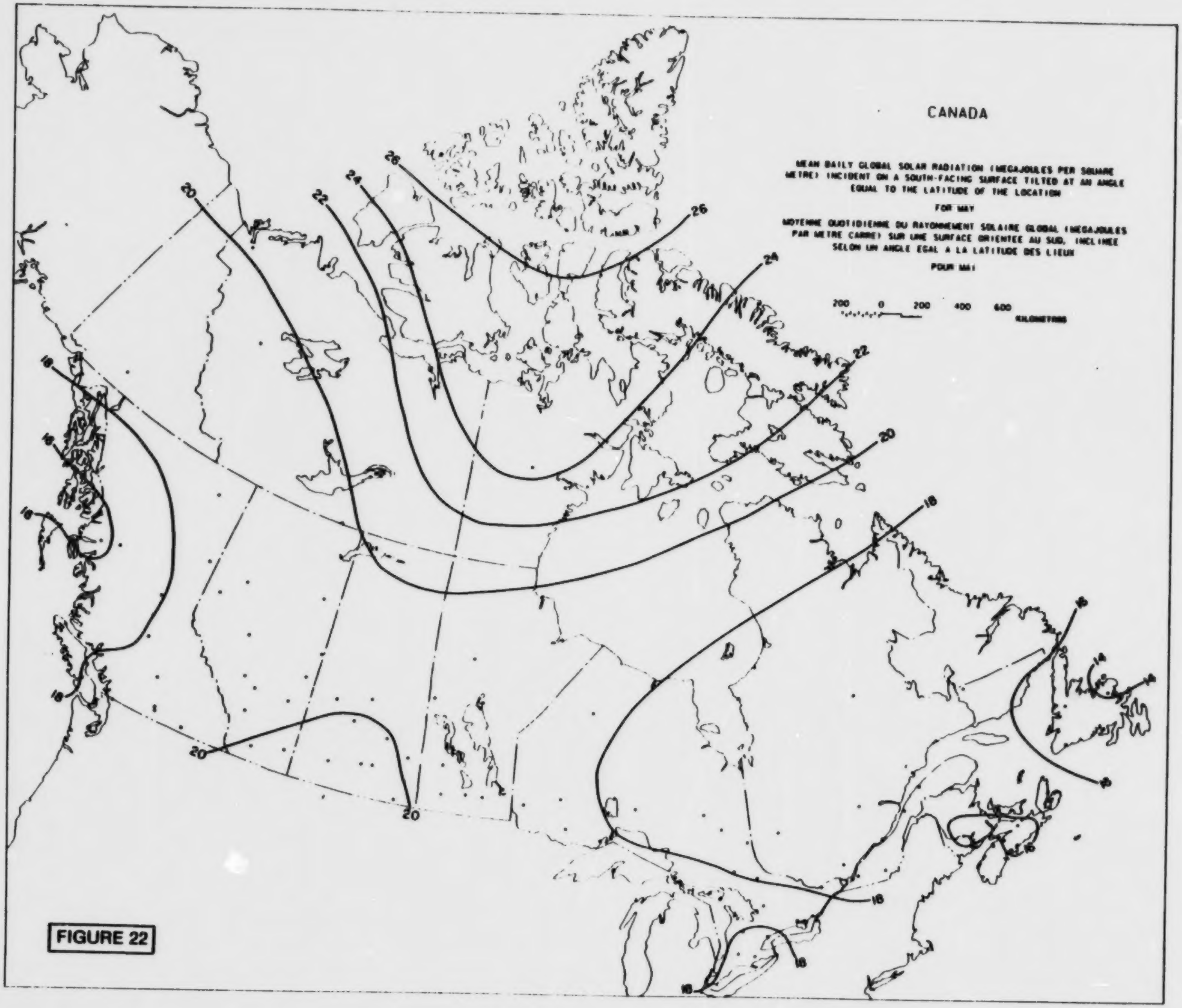
FOR APRIL

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

POUR AVRIL

200 0 200 400 600 KILOMETRES

FIGURE 21



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION

FOR MAY

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

POUR MAI

200 0 200 400 600
KILOMETRES
26
26
24
24
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18
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16
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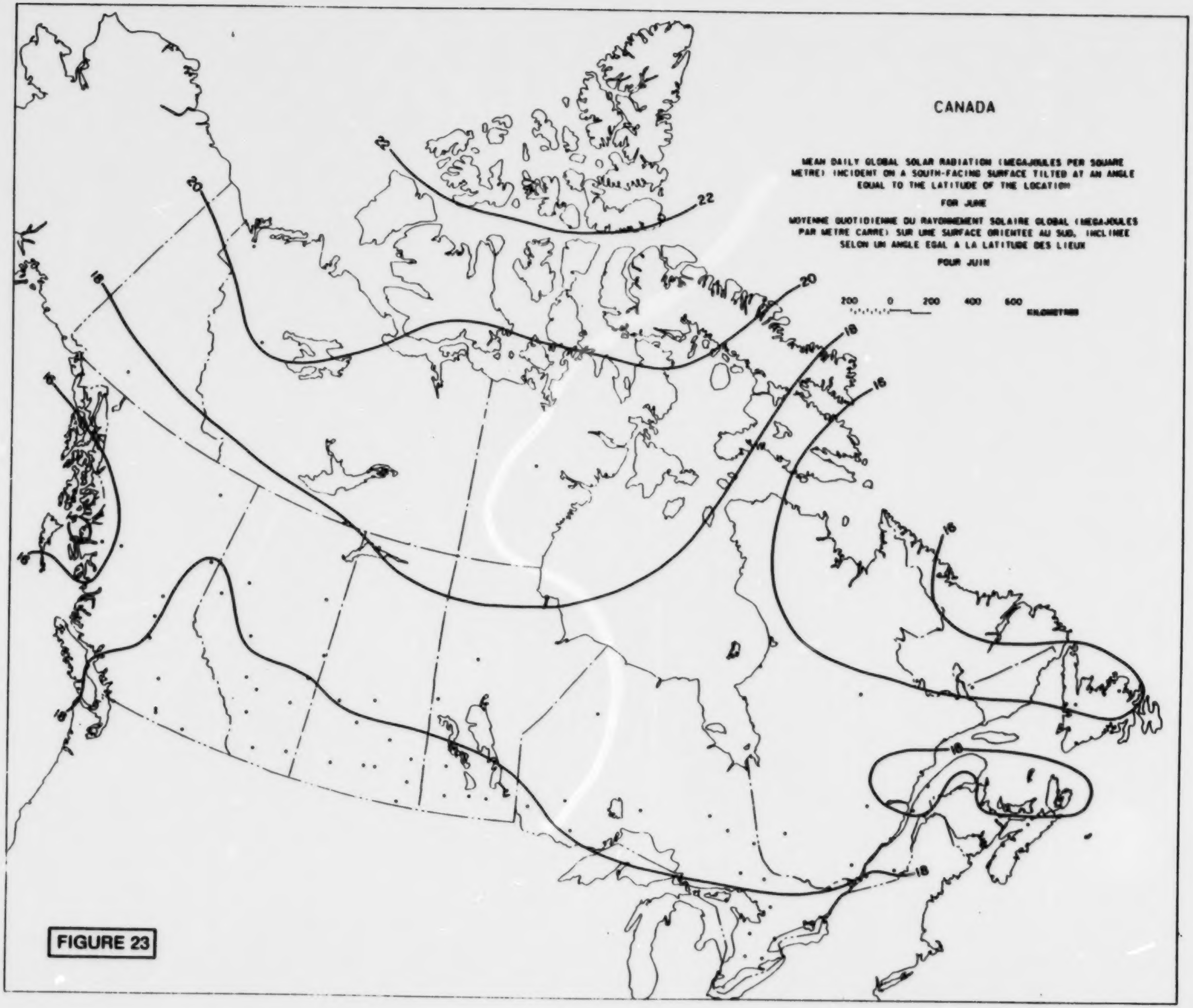
FIGURE 22



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION

FOR JUNE

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

POUR JUIN

200 0 200 400 600
KILOMETRES
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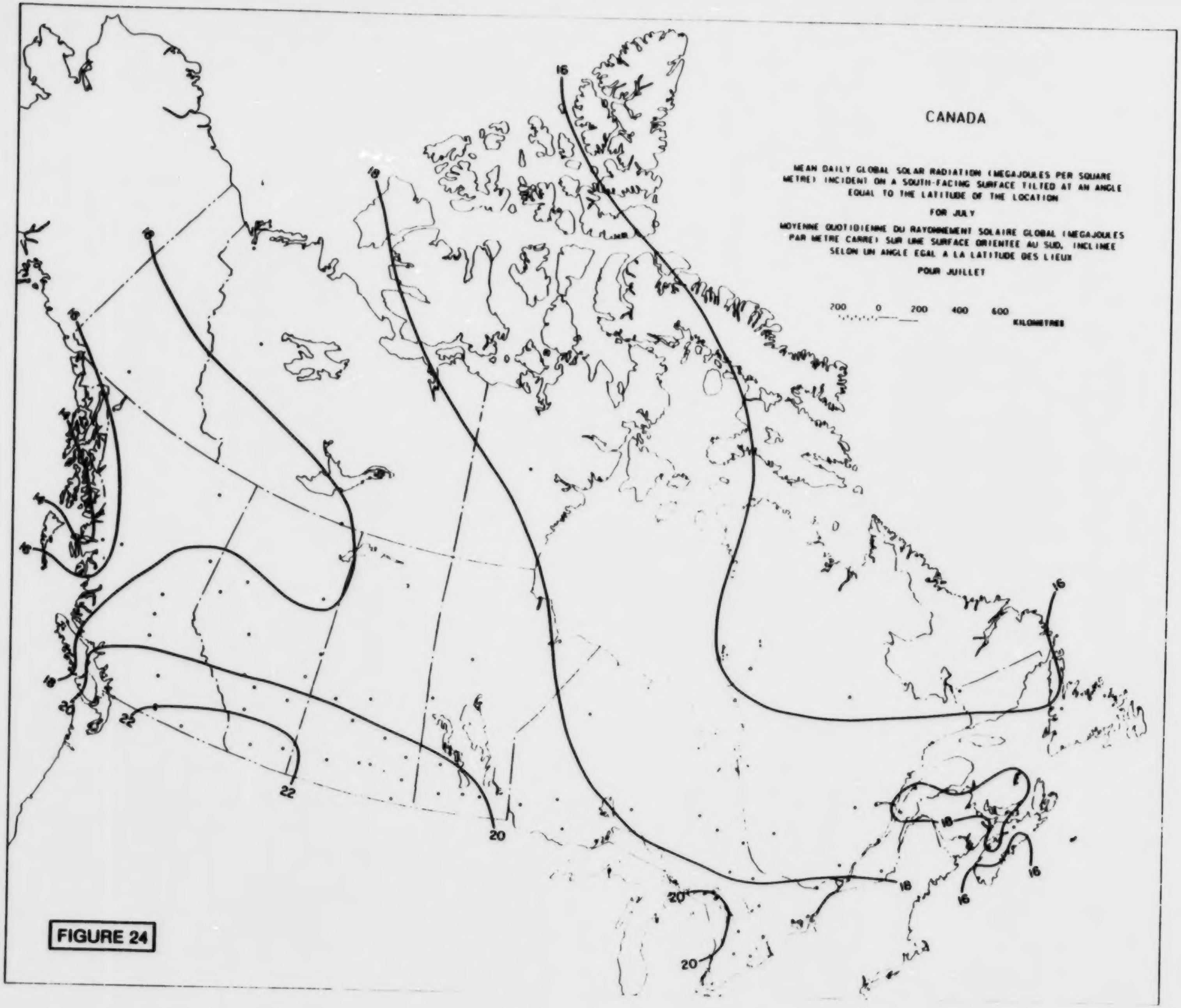
FIGURE 23



CANADA

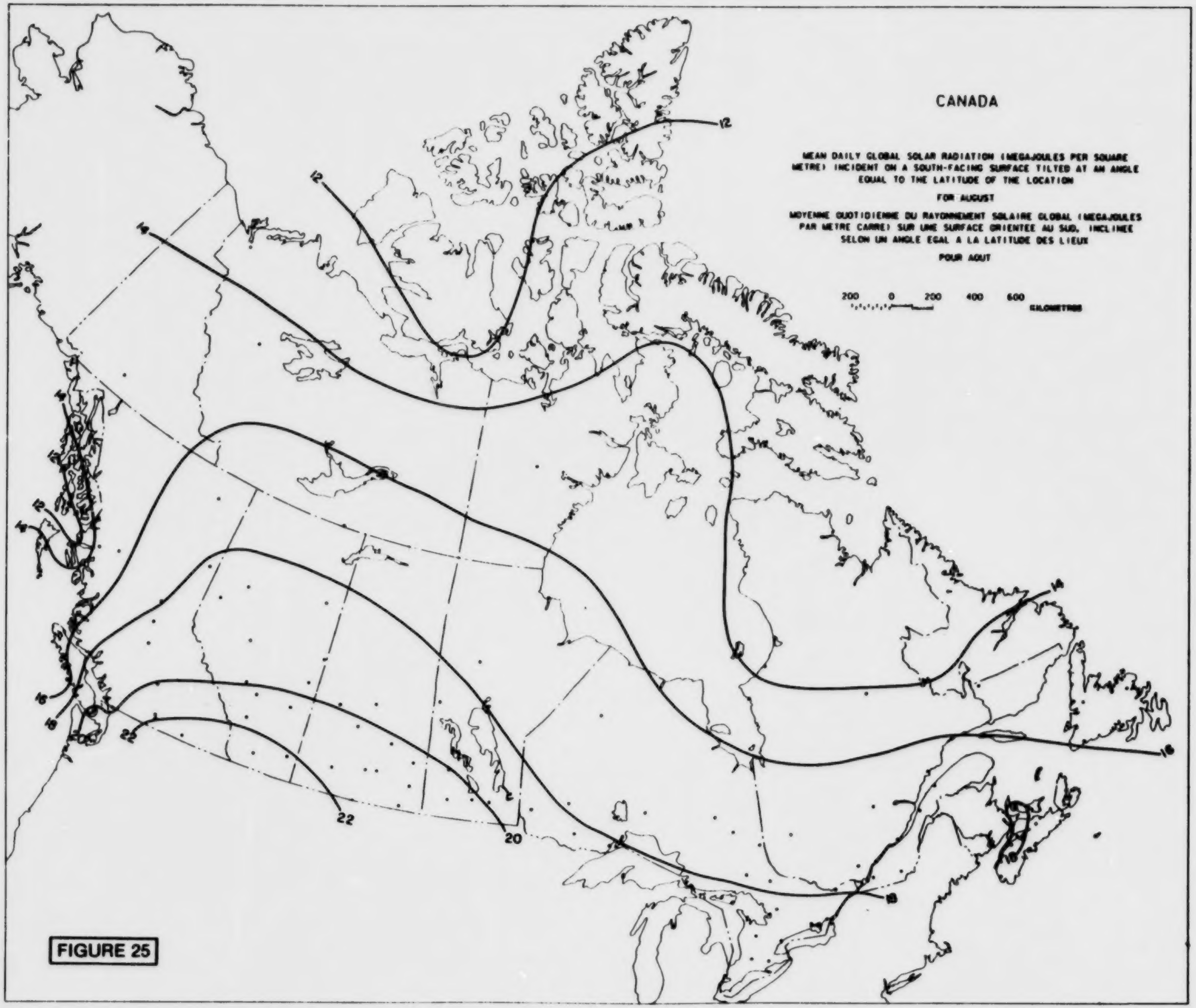
MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION

FOR JULY

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

POUR JUILLET

FIGURE 24



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE
METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE
EQUAL TO THE LATITUDE OF THE LOCATION

FOR AUGUST

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES
PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE
SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

POUR AOUT

200 0 200 400 600
KILOMETRES
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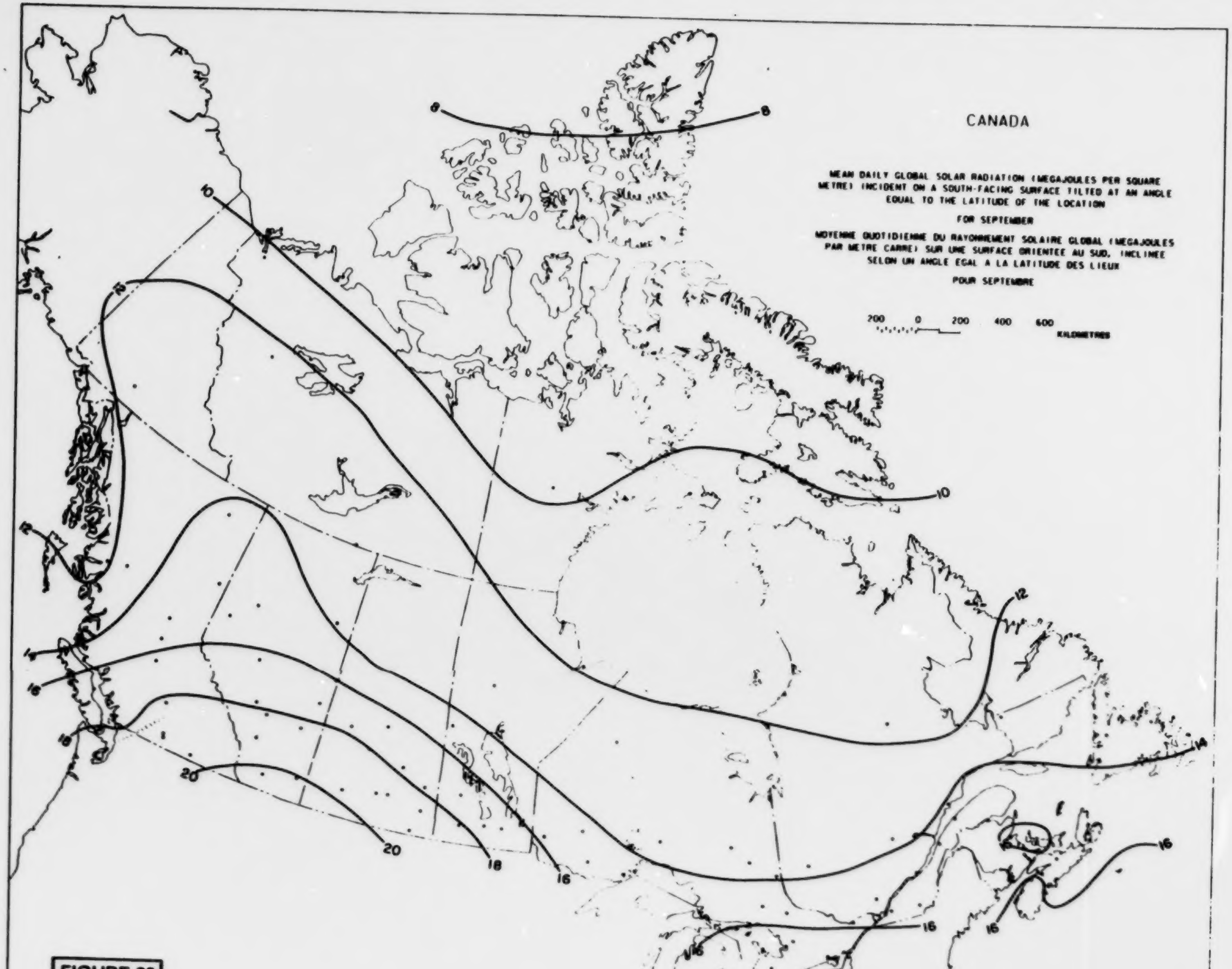
FIGURE 25



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION

FOR SEPTEMBER

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

POUR SEPTEMBRE

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KILOMETRES
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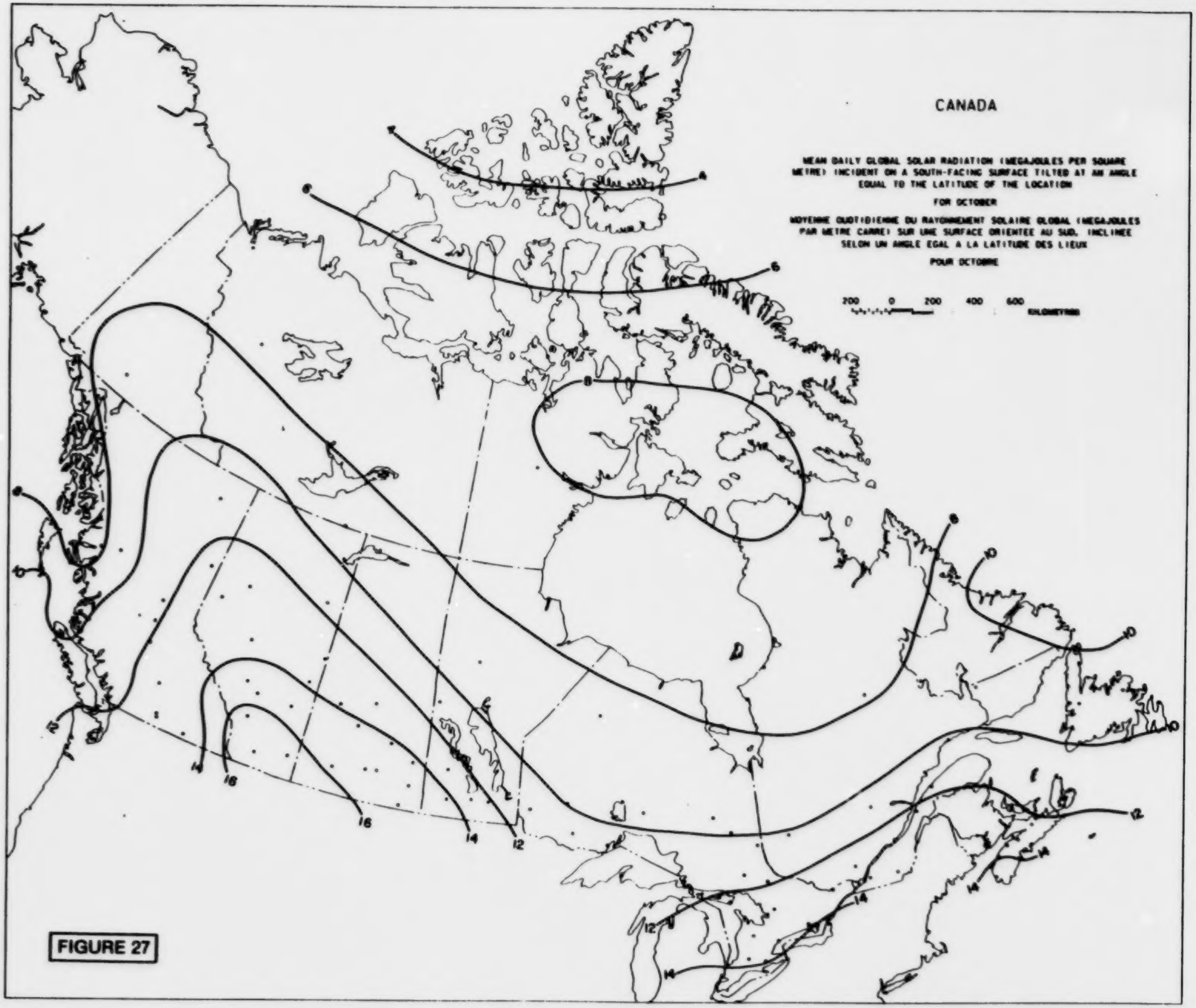
FIGURE 26



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION

FOR OCTOBER

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

POUR OCTOBRE

200 0 200 400 600
KILOMETRES
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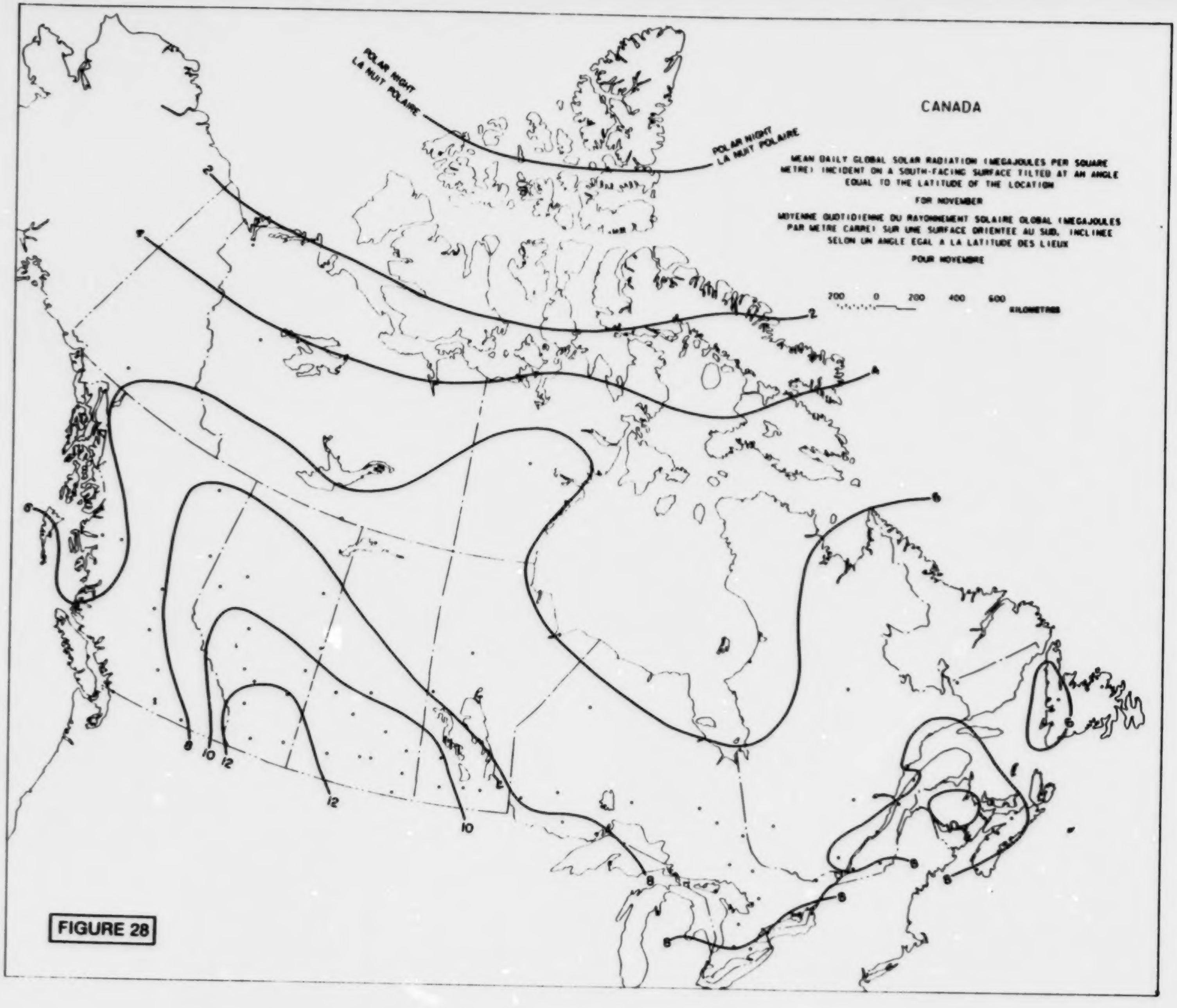
FIGURE 27


POLAR NIGHT
LA NUIT POLAIRE
POLAR NIGHT
LA NUIT POLAIRE
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200 0 200 400 600
KILOMETRES

CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION

FOR NOVEMBER

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

POUR NOVEMBRE

FIGURE 28

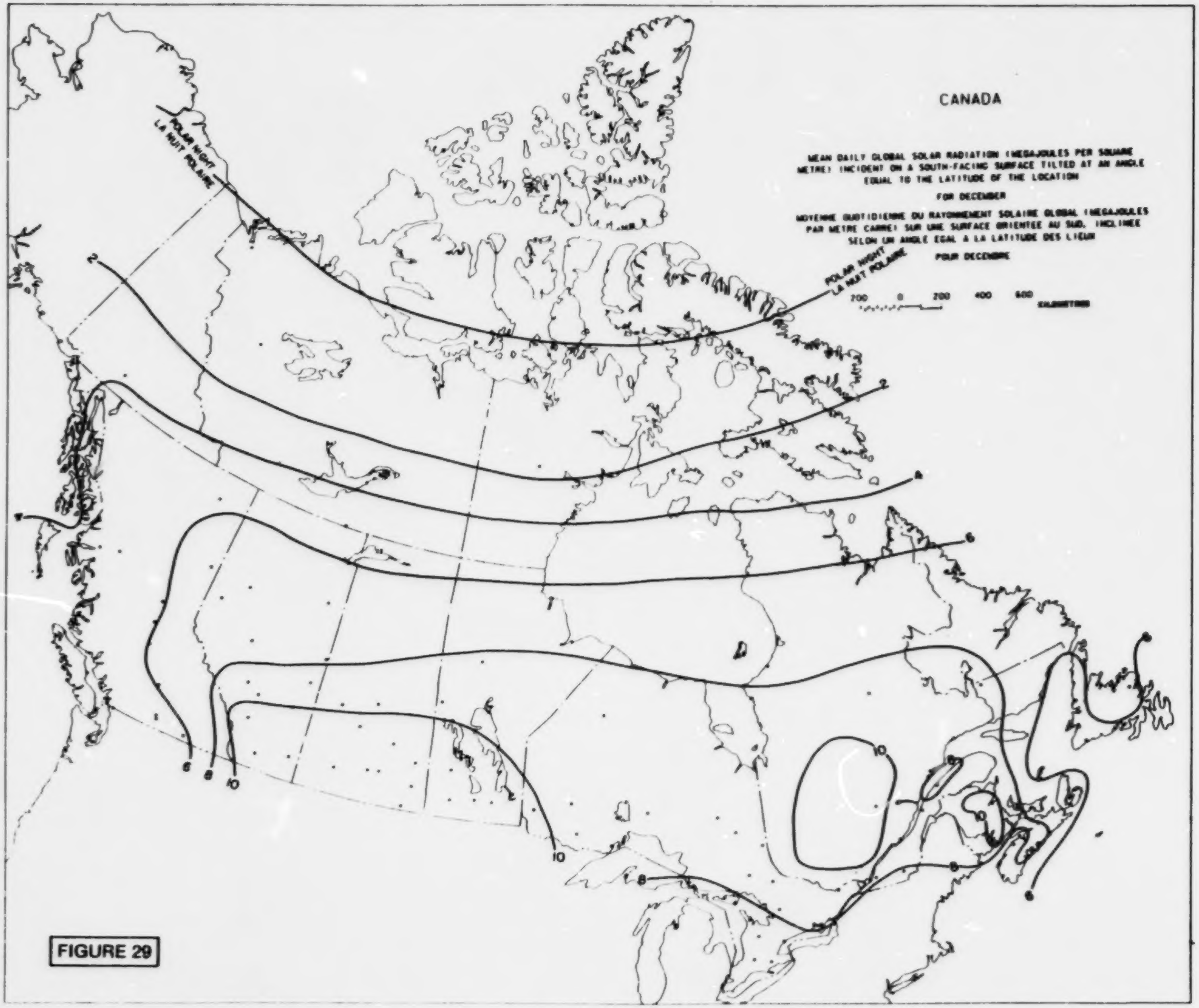

FIGURE 29

CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION

FOR DECEMBER

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX

POUR DECEMBRE

POLAR NIGHT
LA NUIT POLAIRE
200 0 200 400 600
KILOMETRES
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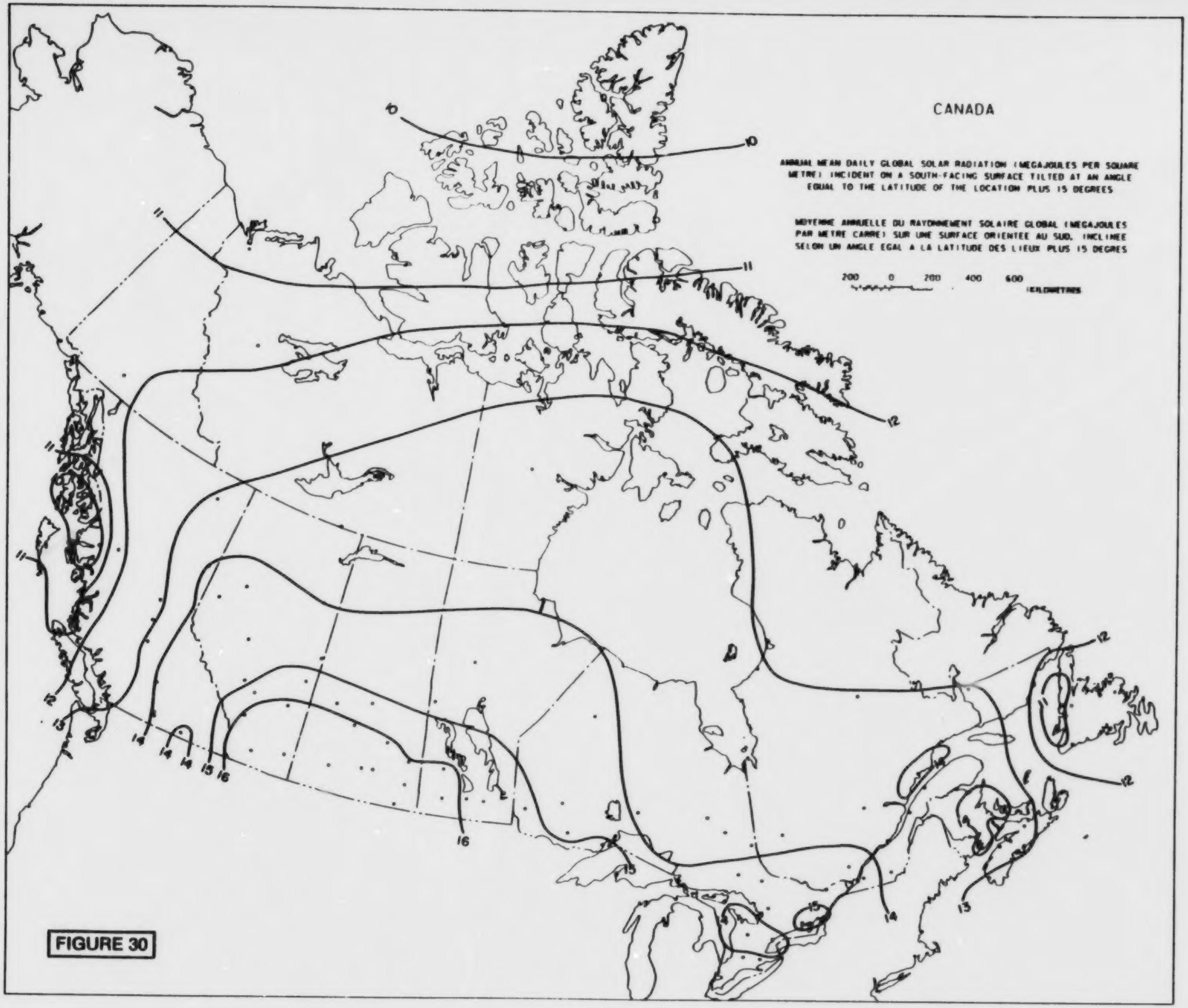

CANADA

ANNUAL MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

MOYENNE ANNUELLE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

200 0 200 400 600
KILOMETRES
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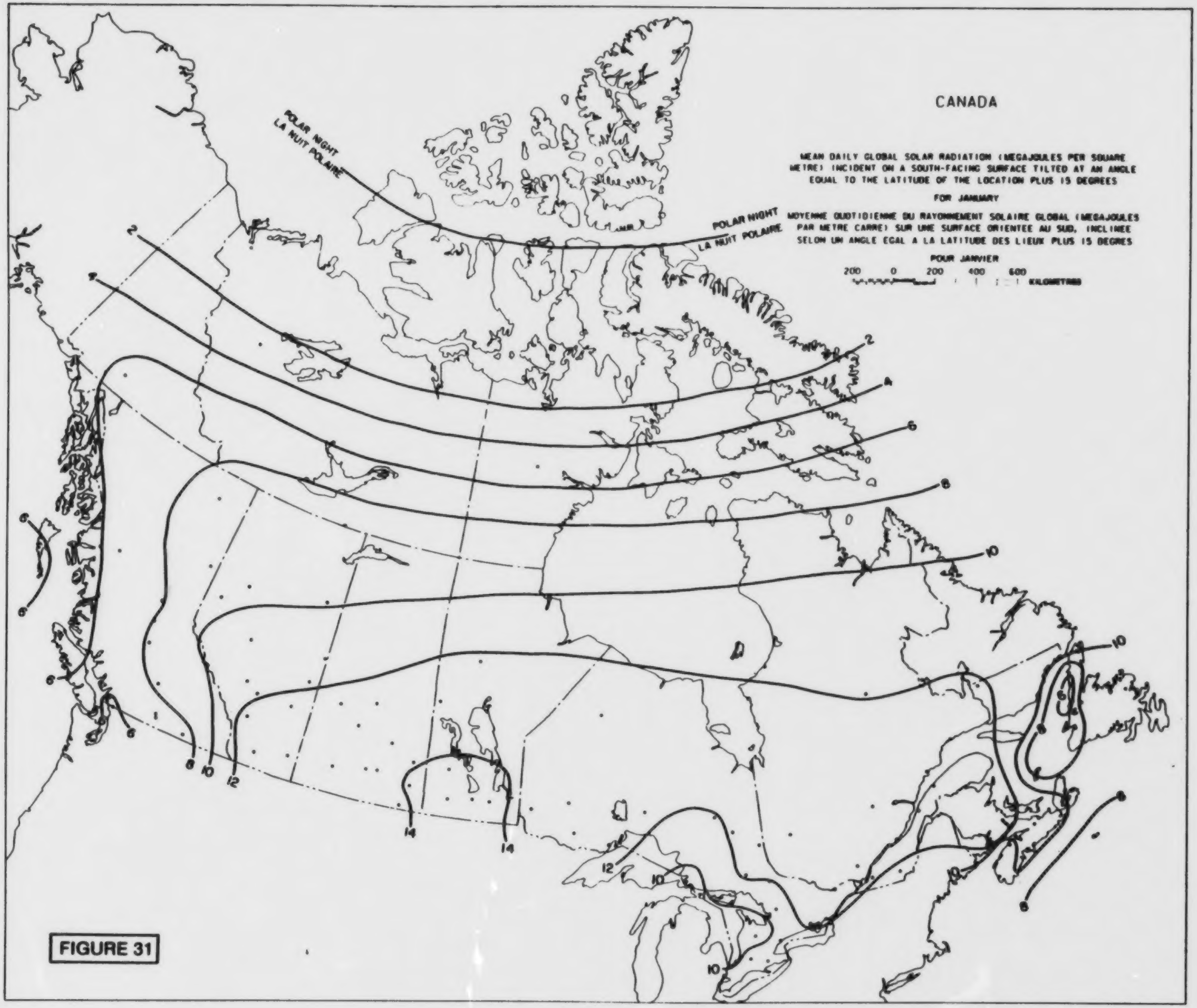
FIGURE 30



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

FOR JANUARY

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

POUR JANVIER

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KILOMETRES
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POLAR NIGHT
LA NUIT POLAIRE
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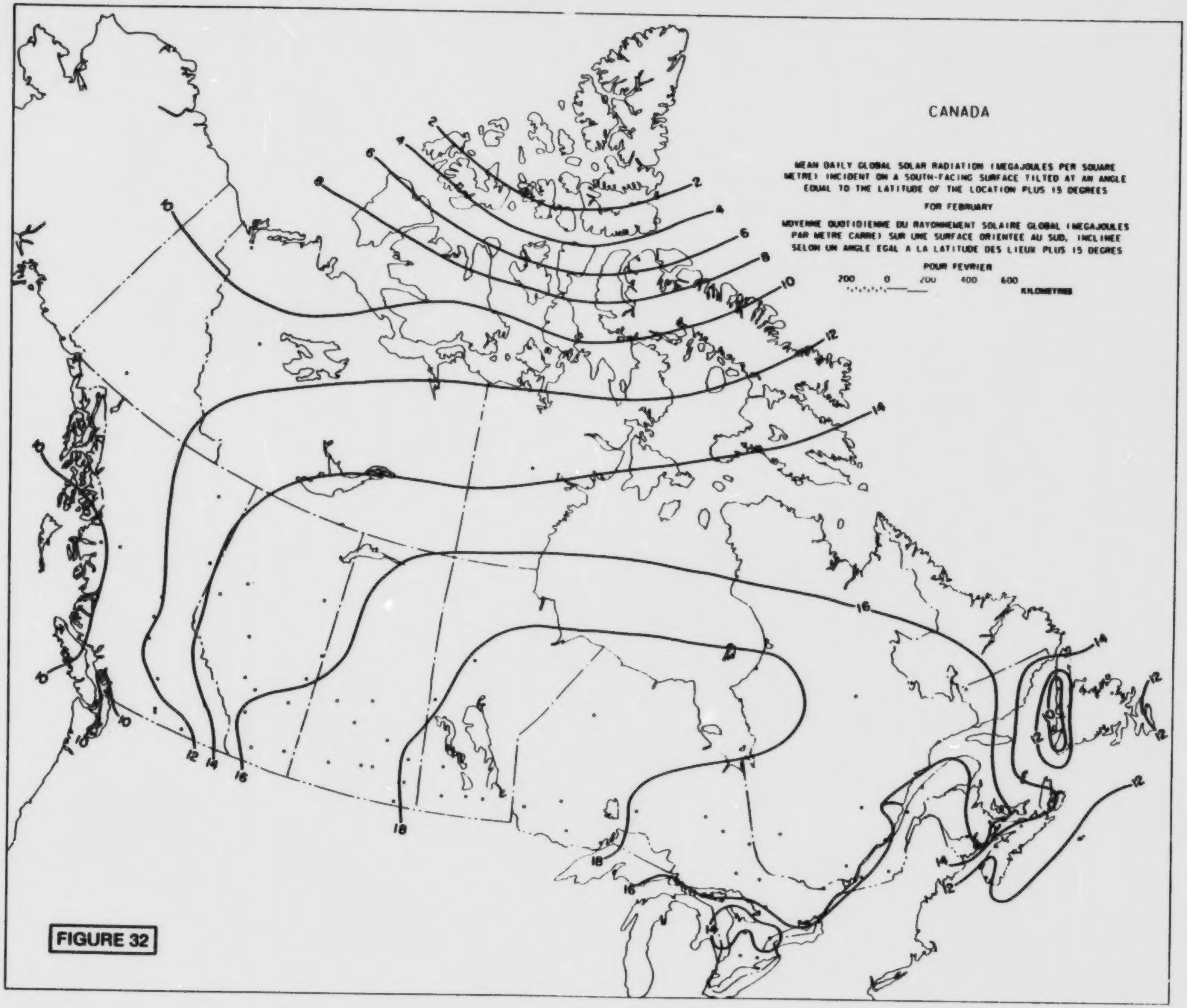
FIGURE 31



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

FOR FEBRUARY

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

POUR FEVRIER

200 0 200 400 600
KILOMETRES
2
4
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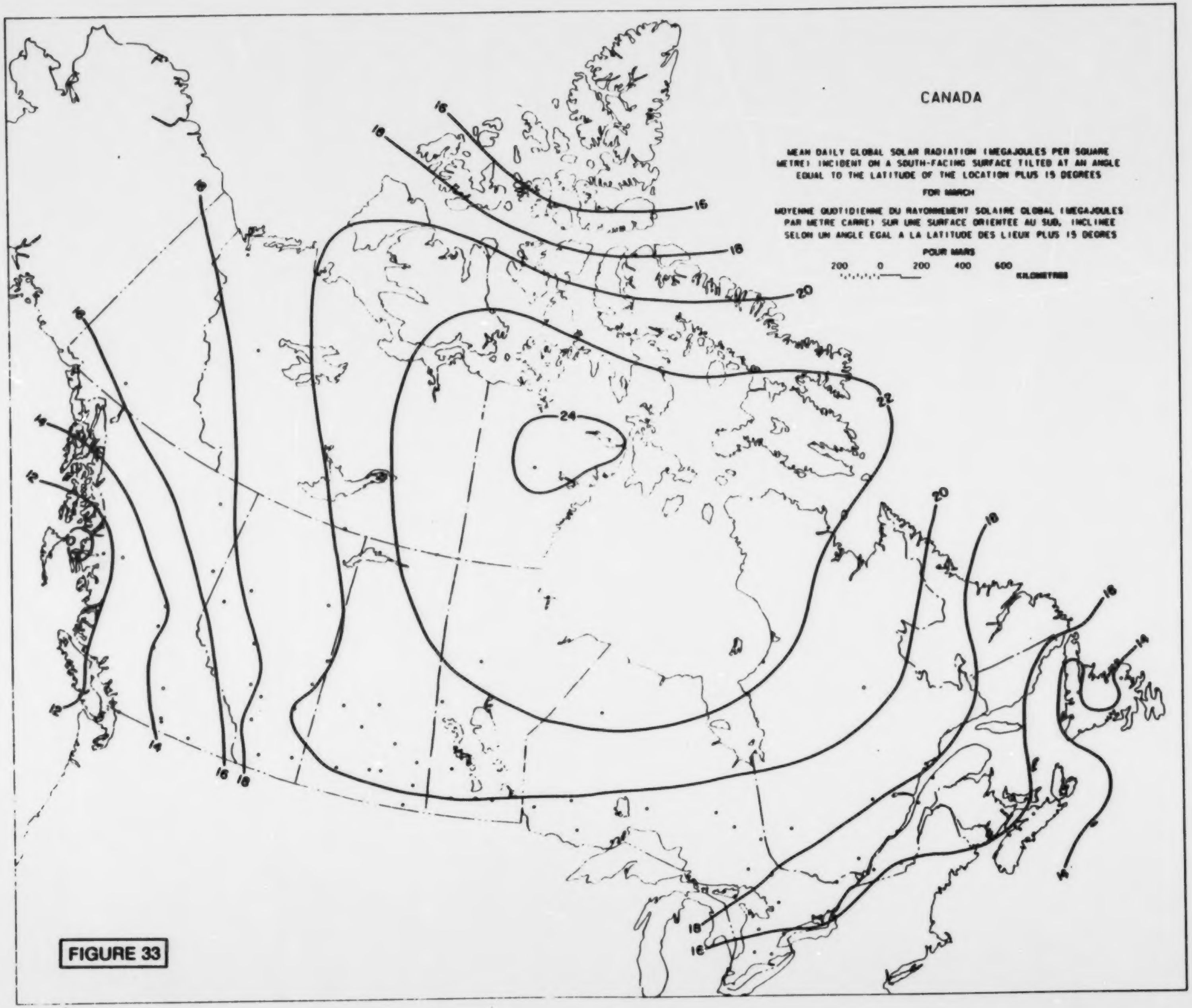
16
18

FIGURE 32


16
18
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18
20
22
24
20
18
16
14
16
18
16
18
16
14
12
12
14
16
18
200 0 200 400 600
KILOMETRES

CANADA

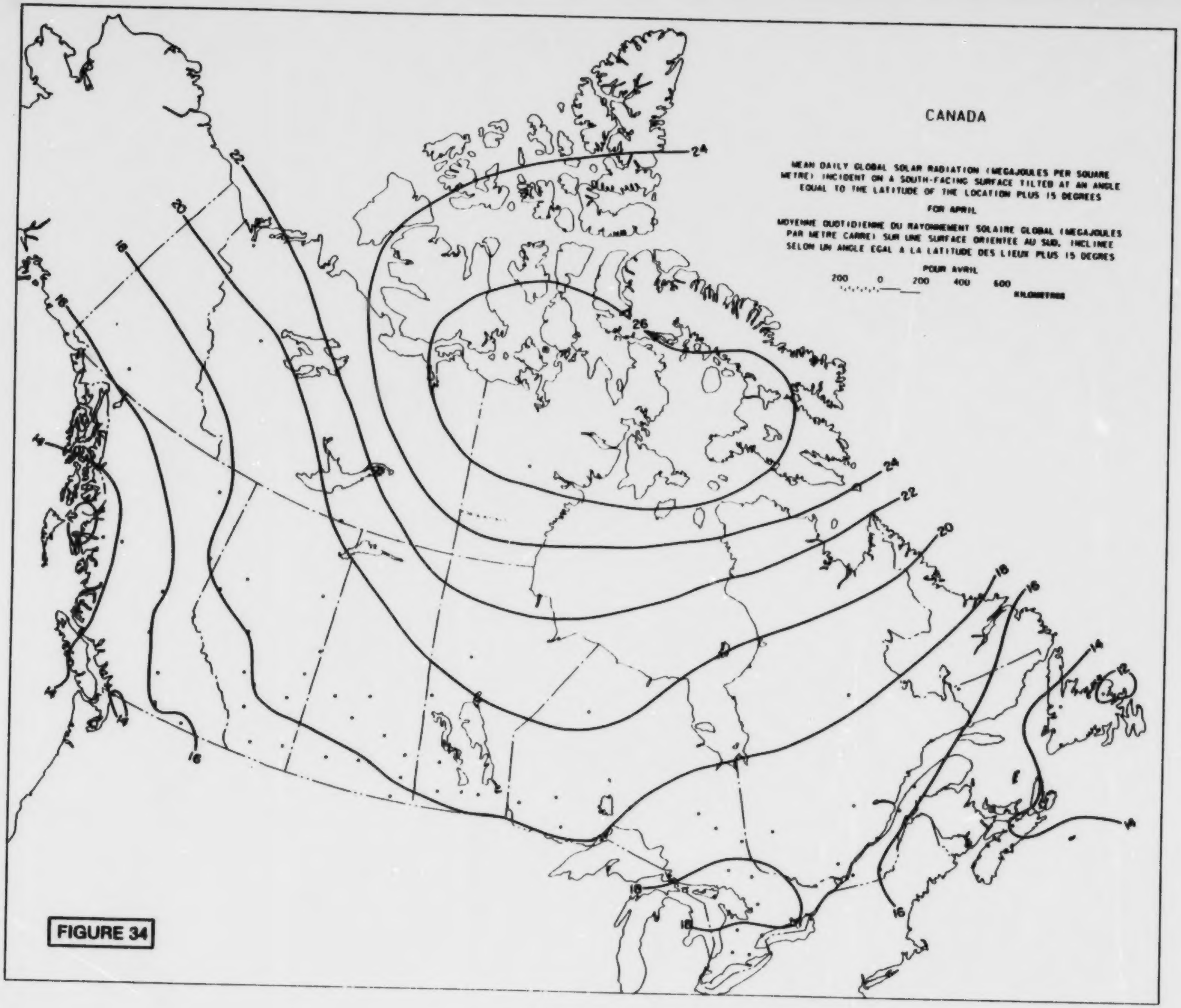
MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

FOR MARCH

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

POUR MARS

FIGURE 33



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

FOR APRIL

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

POUR AVRIL

200 0 200 400 600
KILOMETRES
24
22
20
18
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26
24
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18
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12
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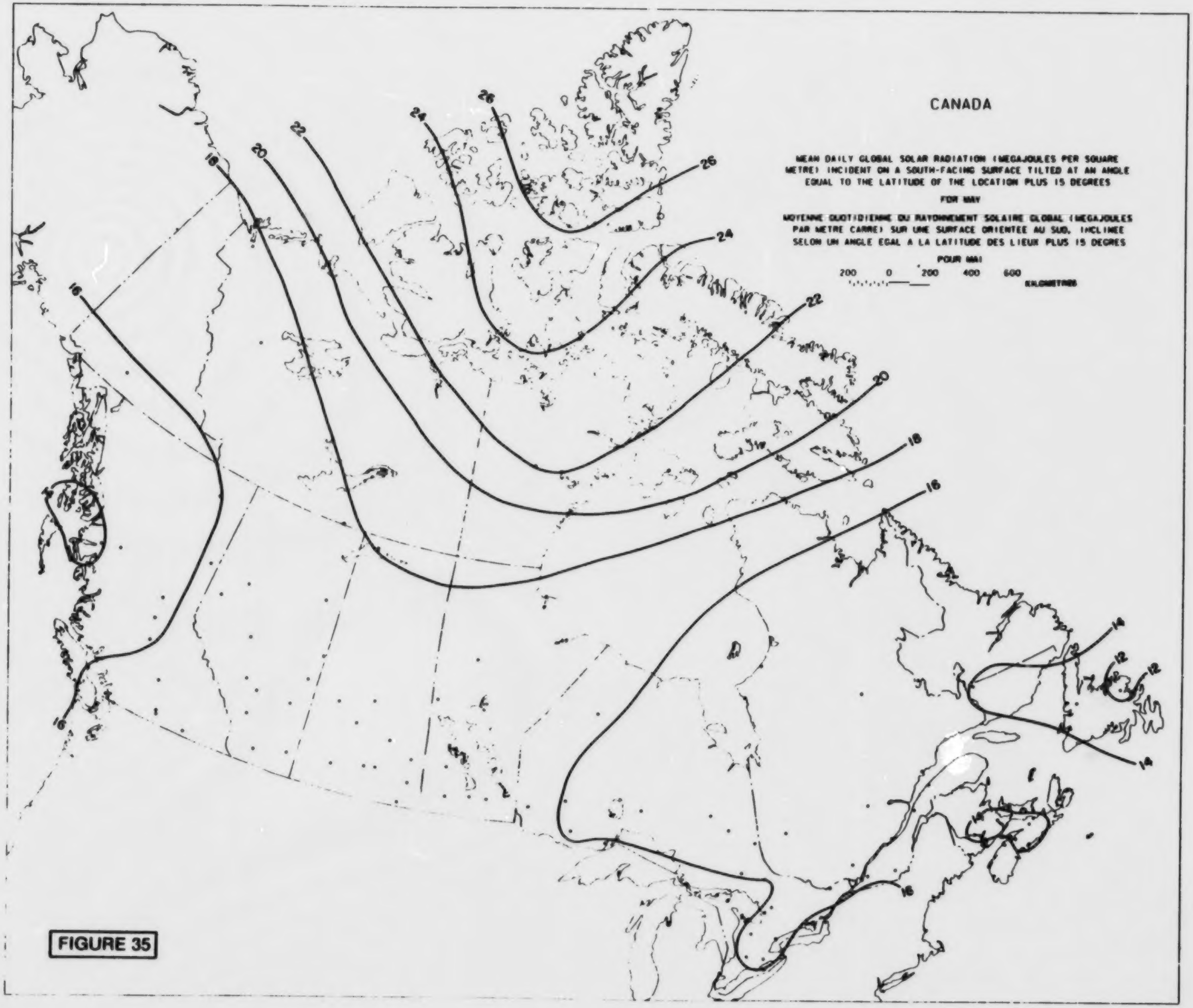
18
18

FIGURE 34



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

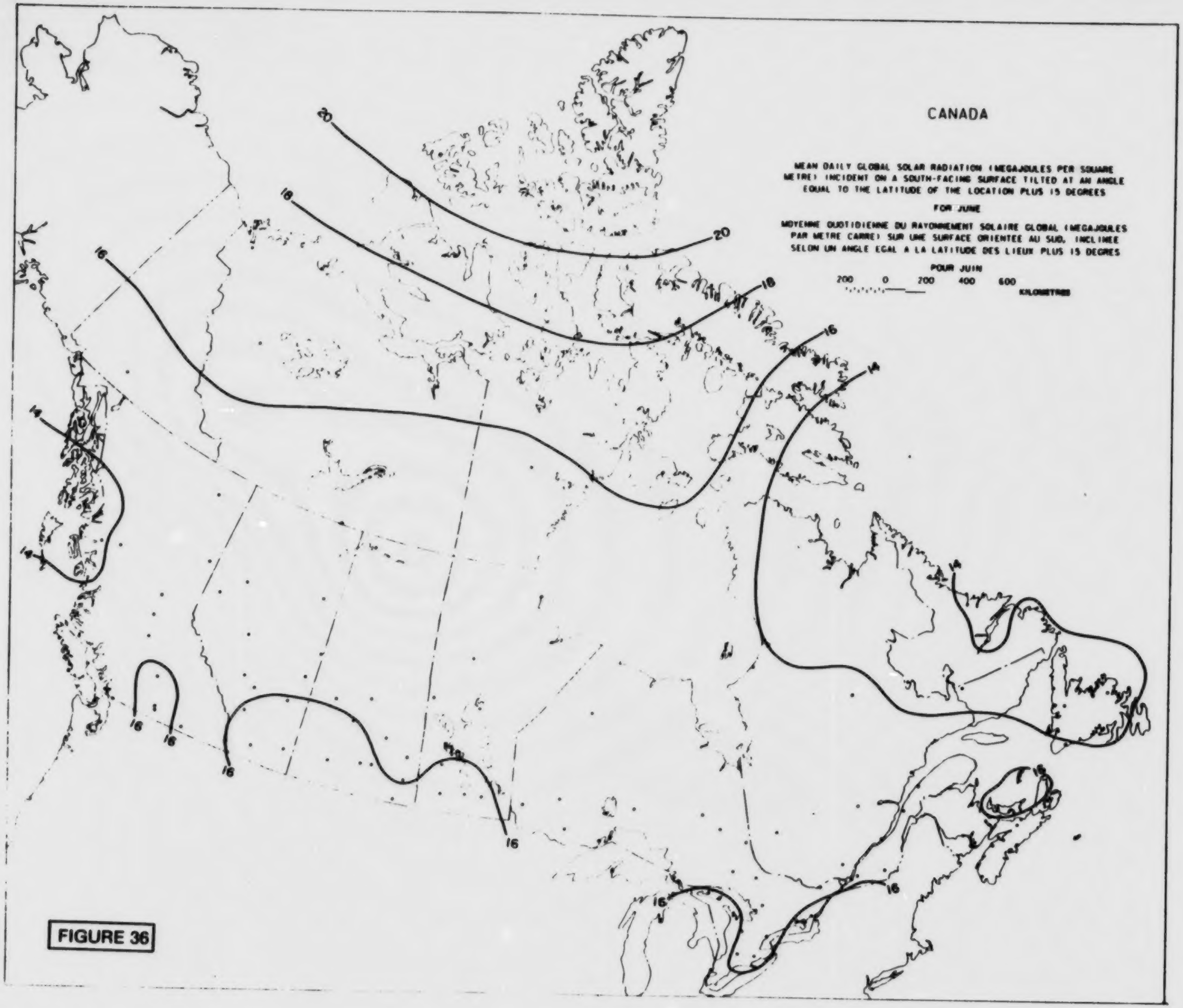
FOR MAY

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

POUR MAI

200 0 200 400 600
KILOMETRES
26
26
24
24
22
22
20
20
18
18
16
16
16
16
14
14
12
12

FIGURE 35


20
20
18
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16
14
14
14
14
16
200 0 200 400 600
KILOMETRES

CANADA

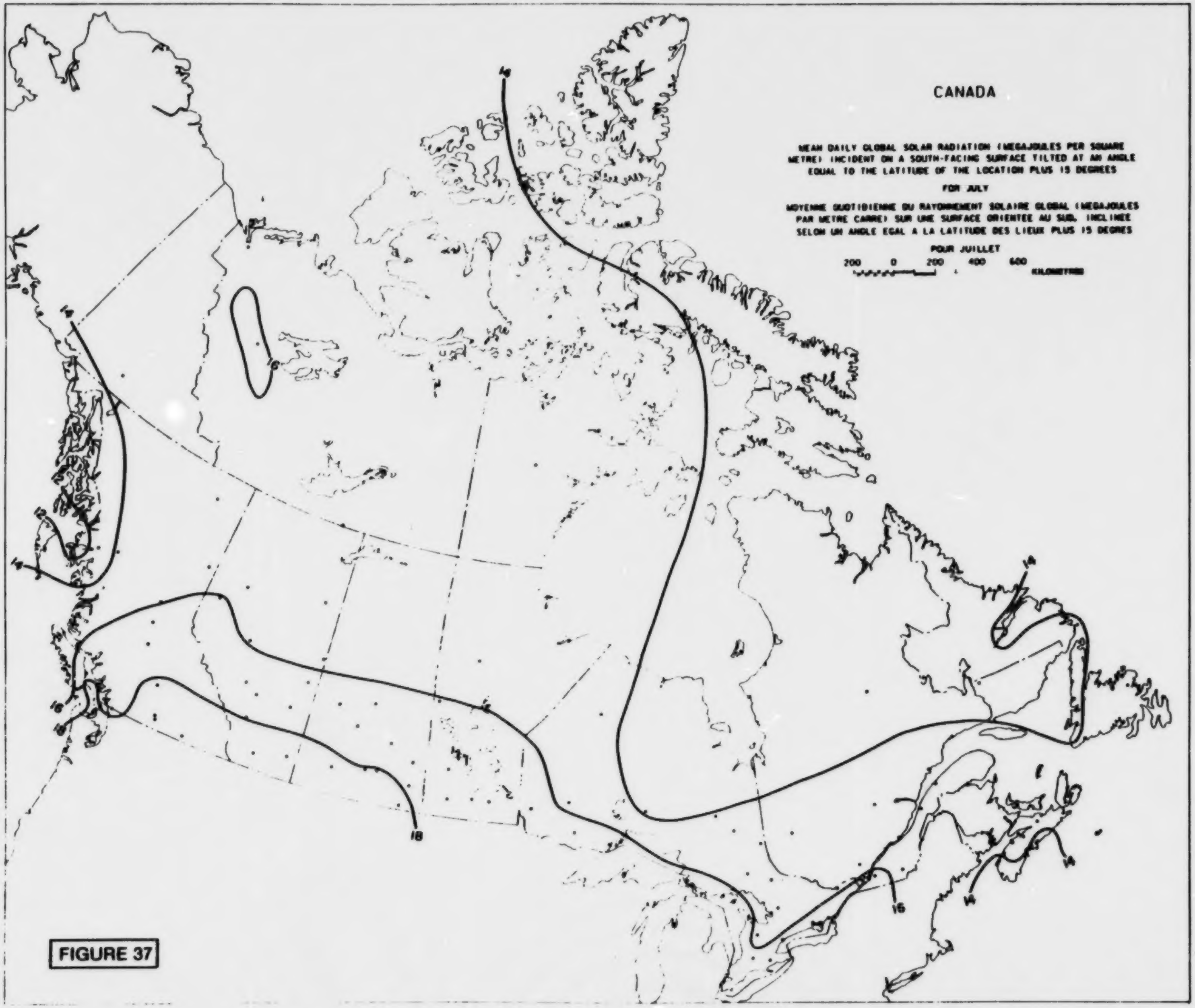
MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

FOR JUNE

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

POUR JUIN

FIGURE 36



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

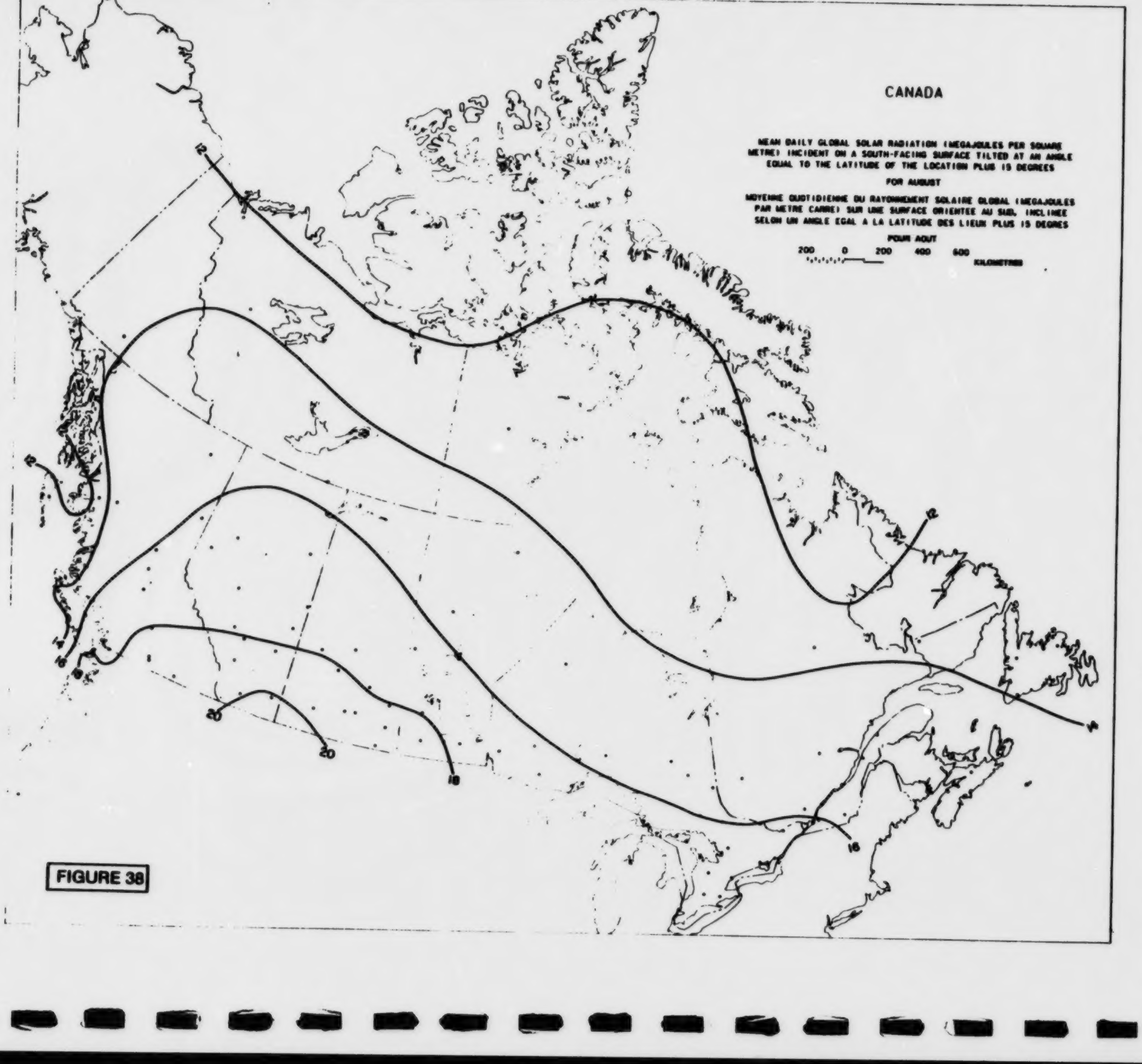
FOR JULY

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

POUR JUILLET

200 0 200 400 600
KILOMETRES
14
14
16
12
14
16
18
16
18
14
16
14
14

FIGURE 37



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

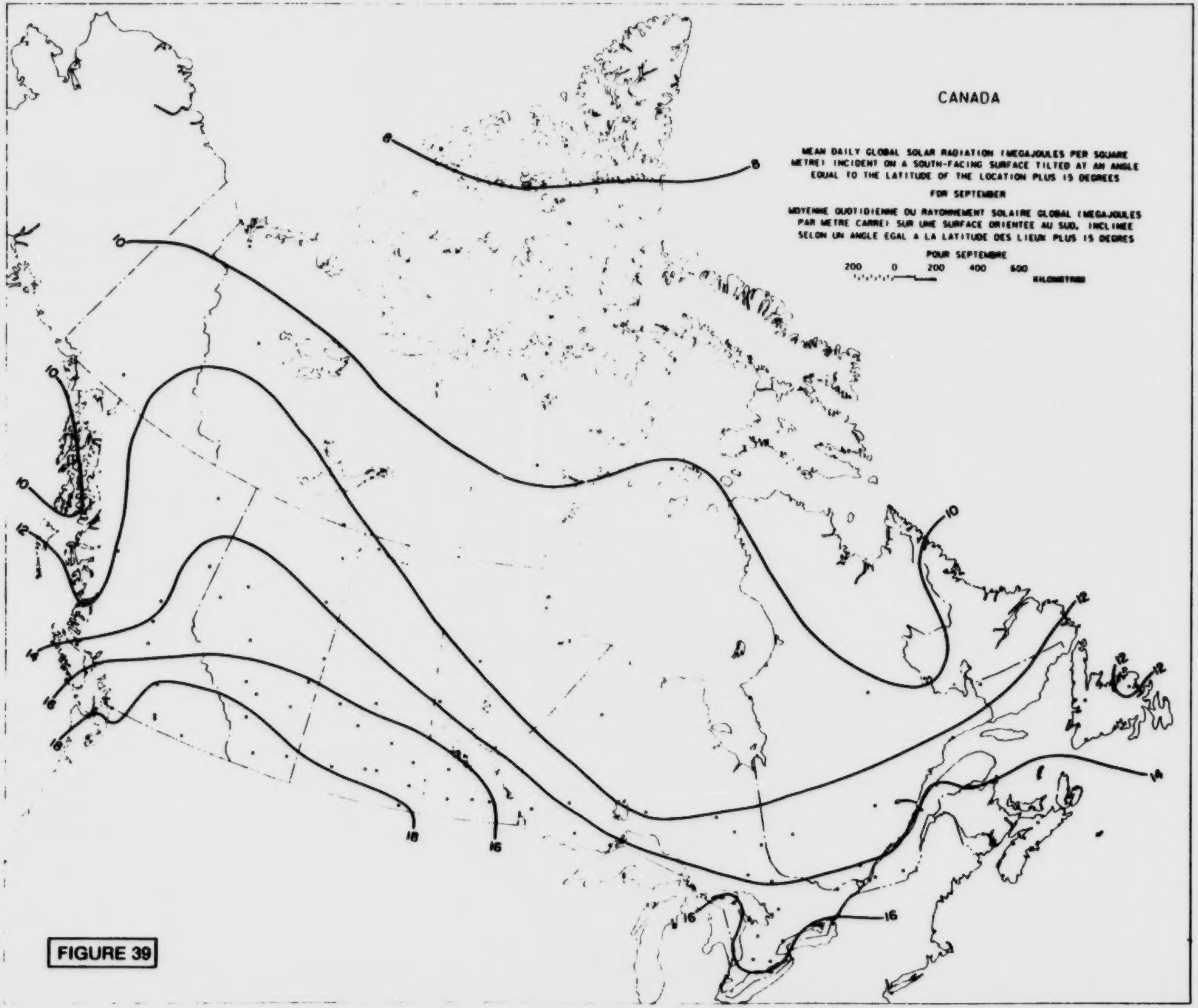
FOR AUGUST

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

POUR AOUT

200
0
200
400
600
KILOMETRES
12
12
12
14
16
16
18
20
20
18
16
4

FIGURE 38


8
8
10
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10
10
12
12
12
12
14
14
16
16
16
16
18
18
200 0 200 400 600
KILOMETRES

CANADA

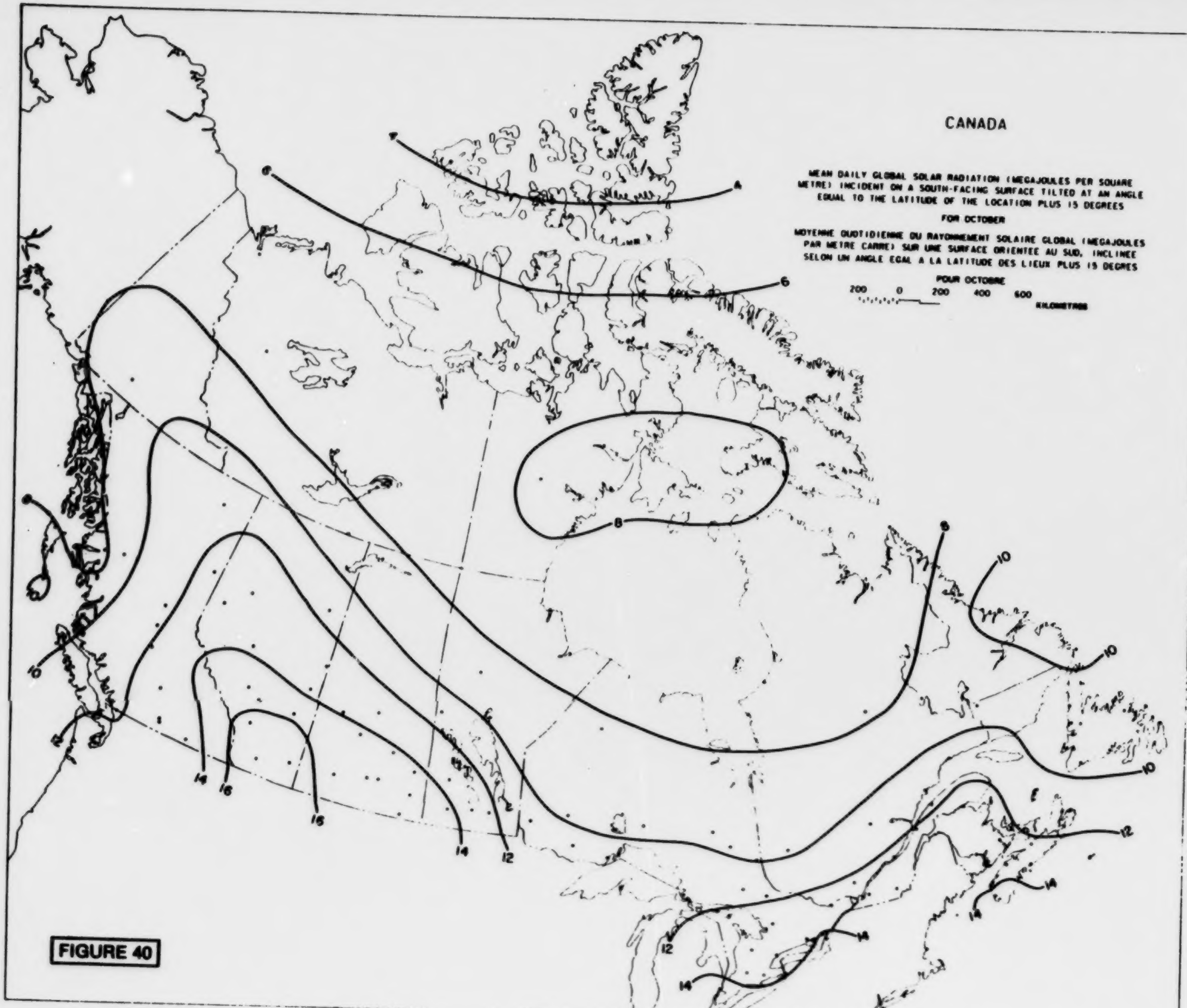
MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

FOR SEPTEMBER

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

POUR SEPTEMBRE

FIGURE 39



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

FOR OCTOBER

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

POUR OCTOBRE

FIGURE 40

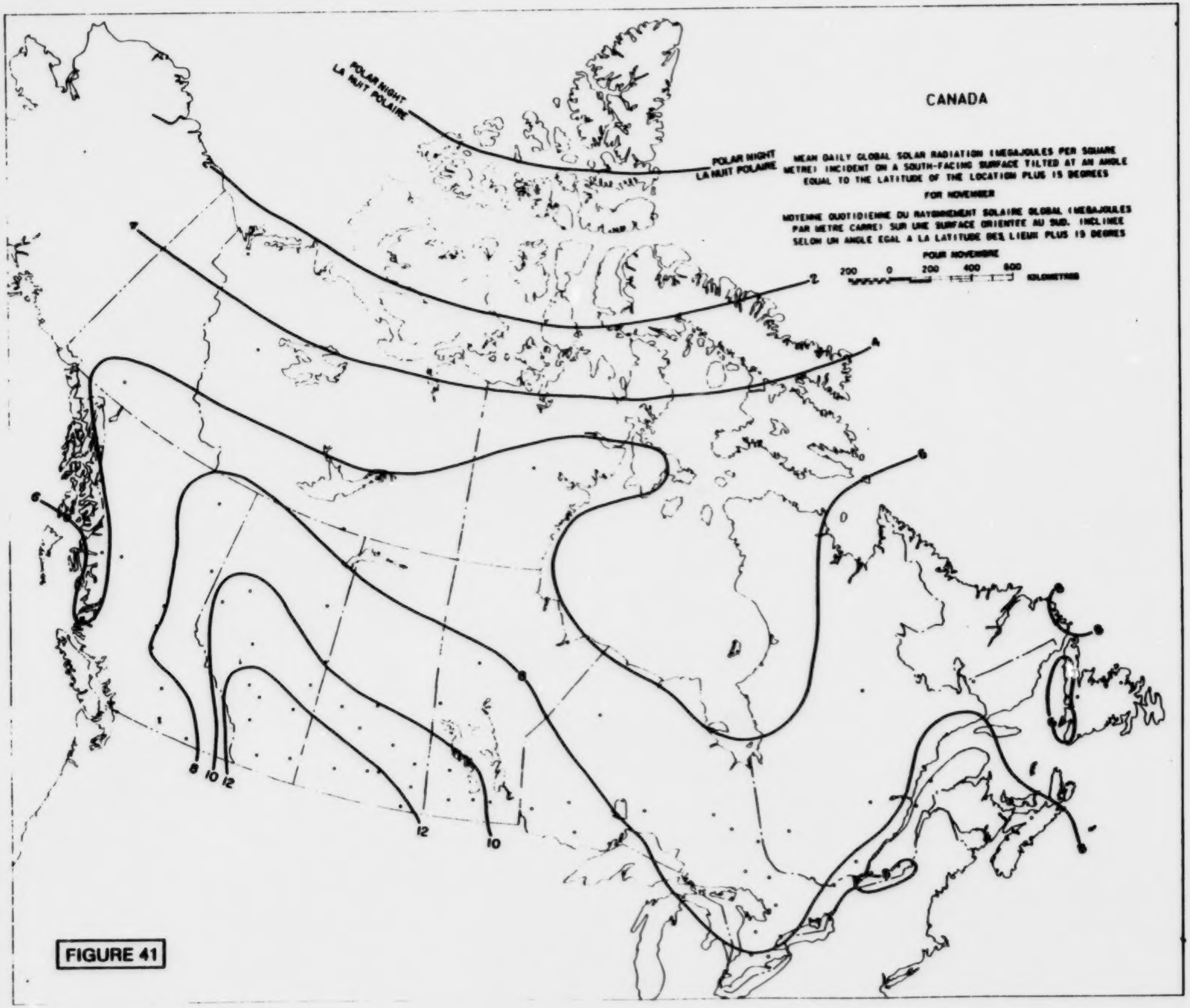


FIGURE 41

CANADA

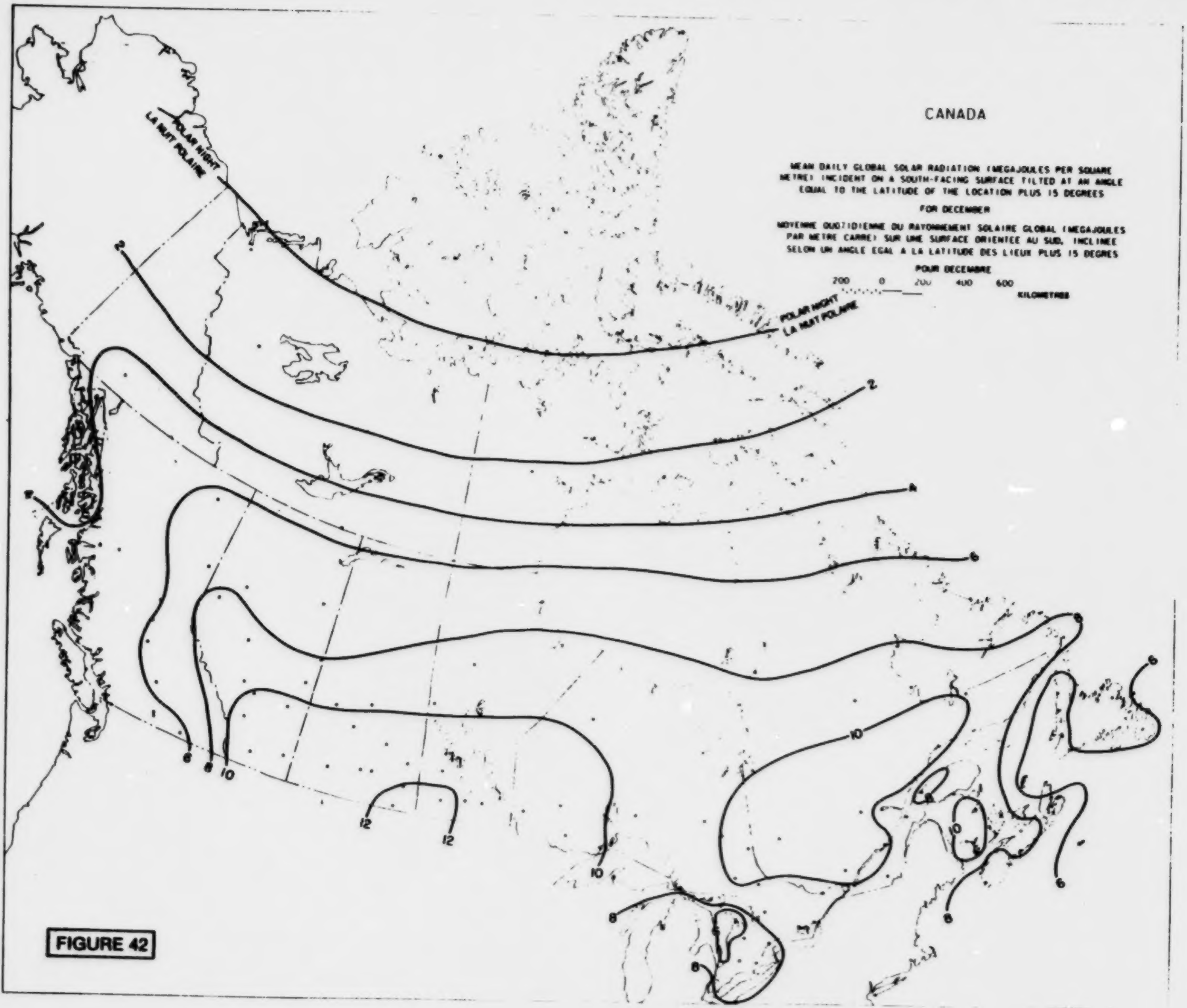
MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

FOR NOVEMBER

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

POUR NOVEMBRE

200 0 200 400 600
KILOMETRES
POLAR NIGHT
LA NUIT POLAIRE
POLAR NIGHT
LA NUIT POLAIRE
2
2
4
4
6
6
6
8
8
10
10
12
12



CANADA

MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH-FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

FOR DECEMBER

MOYENNE QUOTIDIENNE DU RAYONNEMENT SOLAIRE GLOBAL (MEGAJOULES PAR METRE CARRE) SUR UNE SURFACE ORIENTEE AU SUD, INCLINEE SELON UN ANGLE EGAL A LA LATITUDE DES LIEUX PLUS 15 DEGRES

POUR DECEMBRE

200 0 200 400 600
KILOMETRES
POLAR NIGHT
LA NUIT POLAIRE
2
4
6
8
10
12
10
8
6

FIGURE 42

VANCOUVER UBC (BC) (1108487)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	2.827	5.732	9.905	15.025	20.121	21.007	22.770	18.196	13.533	7.128	3.452	2.213	11.850	MEAN
		1.9086	3.4628	5.5890	6.4856	7.0293	7.9458	6.9640	6.3454	5.4230	4.2247	2.2232	1.5428	9.0479	SD
30	0	1.465	2.370	5.283	10.481	15.960	17.745	18.166	12.994	7.281	3.037	1.651	1.102	8.150	MOYEN
		0.7353	1.1435	2.4536	3.6955	4.8135	5.9461	4.9271	3.8622	2.4993	1.6294	0.8368	0.5303	7.1738	EC
60	0	1.299	2.110	3.457	5.709	8.995	11.236	9.992	6.247	3.430	2.438	1.464	0.976	4.785	MEAN
		0.6362	0.9420	1.5345	2.0366	2.3740	2.8681	2.4802	2.0515	1.6417	1.2549	0.7125	0.4535	3.8700	SD
90	0	1.074	1.790	2.966	4.662	6.526	7.633	6.798	4.967	3.152	2.097	1.210	0.806	3.644	MOYEN
		0.5290	0.7158	1.1753	1.4723	1.6170	1.8763	1.6490	1.3979	1.0761	0.9747	0.5644	0.3715	2.6085	EC
30	270	2.831	5.712	9.774	14.582	19.640	20.477	21.919	17.012	13.366	7.071	3.523	2.243	11.606	MEAN
		2.0227	3.5551	5.5073	6.4004	6.8370	7.6712	6.6109	6.2226	5.3021	4.3076	2.3447	1.6694	8.7801	SD
60	270	2.661	5.324	8.838	12.803	17.142	17.762	19.029	15.879	11.967	6.493	3.284	2.142	10.293	MOYEN
		2.0653	3.5118	5.1483	5.8650	6.1845	6.8478	5.8864	5.6872	4.9092	4.1111	2.3243	1.7497	7.7281	EC
90	270	2.205	4.340	7.054	9.936	13.125	13.522	14.538	12.368	9.485	5.218	2.681	1.802	8.034	MEAN
		1.8244	2.9862	4.2288	4.6685	4.8249	5.2898	4.5802	4.5119	4.0077	3.4010	1.9812	1.5782	5.9668	SD
30	225	4.151	7.867	11.961	16.383	20.837	21.047	23.134	19.737	16.280	9.234	5.054	3.505	13.281	MOYEN
		3.6427	5.7221	7.4274	7.7031	7.5730	8.1228	7.2477	7.2490	7.0099	6.1958	3.9632	3.3228	9.4733	EC
60	225	4.661	8.414	11.837	15.046	18.252	17.933	19.896	17.934	15.874	9.583	5.586	4.073	12.432	MEAN
		4.5691	6.6554	7.7747	7.4523	6.7951	6.9445	6.2768	6.7748	7.1712	6.8204	4.7869	4.3151	8.5361	SD
90	225	4.236	7.295	9.585	11.401	13.148	12.549	13.959	13.323	12.531	8.072	4.988	3.781	9.574	MOYEN
		4.3926	6.0063	6.4366	5.7081	4.7824	4.6314	4.2341	4.9826	5.7556	5.9054	4.4662	4.2269	6.3319	EC
30	180	4.737	8.755	12.731	16.769	20.561	20.517	22.812	19.762	17.227	10.019	5.682	4.091	13.650	MEAN
		4.3780	6.6772	8.2338	8.0911	7.6138	8.0418	7.2855	7.4790	7.6697	6.9809	4.6875	4.0913	9.5330	SD
60	180	5.675	9.912	12.918	15.270	17.227	16.541	18.614	17.378	17.022	10.843	6.669	5.088	12.764	MOYEN
		5.8478	8.2758	8.9321	7.7244	6.3801	6.3067	5.8451	6.7409	7.9990	8.0849	6.0485	5.6469	8.5364	EC
90	180	5.382	8.893	10.439	10.924	11.063	10.157	11.274	11.679	13.101	9.325	6.195	4.939	9.439	MEAN
		5.8376	7.7379	7.3979	5.4285	3.6744	3.2589	3.0488	4.2984	6.2284	7.1567	5.8719	5.7459	6.2100	SD
30	135	4.060	7.643	11.567	15.824	19.809	19.989	22.242	18.681	15.727	8.799	4.863	3.467	12.736	MOYEN
		3.5511	5.6011	7.3796	7.6082	7.5143	8.0454	7.3080	7.2182	6.9459	6.0099	3.8567	3.2727	9.1757	EC
60	135	4.504	8.035	11.199	14.207	16.753	16.478	18.653	16.380	15.003	8.855	5.256	4.007	11.618	MEAN
		4.4136	6.4706	7.7029	7.3003	6.6898	6.8244	6.3822	6.7680	7.1052	6.5321	4.6203	4.2290	8.1504	SD
90	135	4.058	6.884	8.919	10.609	11.846	11.359	12.903	11.918	11.662	7.286	4.619	3.705	8.816	MOYEN
		4.2193	5.8205	6.3614	5.5628	4.6853	4.4877	4.3119	4.9954	5.7188	5.6009	4.2872	4.1308	6.0206	EC
30	90	2.730	5.447	9.289	13.831	18.193	18.926	20.626	16.456	12.651	6.541	3.305	2.202	10.867	MEAN
		1.9152	3.3958	5.4506	6.2470	6.7573	7.5193	6.6846	6.1397	5.2060	4.0374	2.1911	1.6211	8.3128	SD
60	90	2.522	4.963	8.185	11.791	15.213	15.691	17.299	13.933	11.027	5.777	2.992	2.085	9.304	MOYEN
		1.9116	3.3079	5.0832	5.6546	6.1044	6.6138	6.0162	5.6354	4.8350	3.7520	2.1253	1.6821	7.1274	EC
90	90	2.076	4.014	6.470	9.050	11.492	11.748	13.042	10.677	8.659	4.581	2.410	1.747	7.174	MEAN
		1.6777	2.8100	4.1828	4.5011	4.7724	5.0699	4.6951	4.4856	3.9695	3.0941	1.8038	1.5118	5.4681	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

VANCOUVER UBC (BC/CB) LATITUDE 49 DEG 15 MIN LONGITUDE 123 DEG 15 MIN PERIOD/PERIODE 1967-1976

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE														
O DEG.	2.827	5.732	9.905	15.025	20.121	21.007	22.770	18.196	13.533	7.128	3.452	2.213	11.855	MEAN
	1.912	3.469	5.598	6.497	7.042	7.960	6.977	6.357	5.432	4.232	2.227	1.545	9.045	S.D.
LATITUDE	5.475	9.744	13.171	16.180	18.852	18.361	20.626	18.691	17.549	10.820	6.474	4.856	13.410	MOYEN
	5.486	7.950	8.954	8.111	7.055	7.159	6.582	7.248	8.143	7.930	5.726	5.251	9.079	EC.T.
LAT.+15 DEG	5.711	9.900	12.721	14.805	16.468	15.715	17.693	16.731	16.679	10.768	6.686	5.140	12.422	MEAN
	5.951	8.348	8.863	7.518	6.067	5.926	5.497	6.491	7.885	8.092	6.122	5.764	8.262	S.D.
90 DEG.	5.382	8.893	10.439	10.924	11.064	10.158	11.278	11.679	13.101	9.325	6.187	4.939	9.442	MOYEN
	5.847	7.752	7.410	5.438	3.681	3.265	3.050	4.306	6.239	7.169	5.873	5.755	6.207	EC.T.
9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE														
O DEG.	2.558	4.783	7.442	10.404	12.868	13.045	14.215	12.041	9.855	5.753	3.068	2.053	8.189	MEAN
	1.749	2.878	4.206	4.636	4.649	5.156	4.361	4.235	3.928	3.409	1.979	1.459	5.683	S.D.
LATITUDE	4.783	7.868	9.899	11.734	13.189	12.672	14.427	13.334	13.056	8.538	5.557	4.312	9.951	MOYEN
	4.821	6.396	6.817	6.161	5.316	5.429	4.929	5.441	6.122	6.261	4.896	4.682	6.637	EC.T.
LAT.+15 DEG	4.963	7.945	9.557	10.858	11.794	11.145	12.759	12.169	12.467	8.457	5.707	4.538	9.364	MEAN
	5.205	6.684	6.756	5.796	4.743	4.706	4.324	5.009	5.967	6.361	5.210	5.113	6.238	S.D.
90 DEG.	4.638	7.061	7.833	8.169	8.152	7.400	8.439	8.752	9.880	7.260	5.233	4.322	7.257	MOYEN
	5.076	6.150	5.650	4.312	3.046	2.783	2.596	3.483	4.772	5.588	4.960	5.065	4.873	EC.T.
RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE														
O DEG.	.894	.833	.749	.685	.635	.613	.623	.660	.726	.803	.884	.918	.752	MEAN
	.049	.051	.061	.072	.061	.060	.044	.055	.055	.063	.048	.037	.121	S.D.
LATITUDE	.864	.808	.744	.709	.687	.672	.689	703	.736	.783	.856	.884	.761	MOYEN
	.076	.067	.069	.075	.062	.068	.049	.058	.060	.078	.066	.066	.098	EC.T.
LAT.+15 DEG	.859	.803	.743	.716	.701	.689	.709	.715	.739	.779	.851	.879	.765	MEAN
	.082	.071	.071	.075	.064	.073	.053	.059	.061	.081	.071	.073	.095	S.D.
90 DEG.	.851	.795	.742	.728	.721	.709	.735	.735	.744	.773	.843	.871	.771	MOYEN
	.092	.077	.072	.075	.068	.080	.061	.061	.061	.086	.079	.083	.092	EC.T.

PRINCE GEORGE A (BC) (1096450)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	2.884	5.705	9.823	15.339	18.697	20.308	20.434	16.792	10.892	6.236	2.979	2.082	11.034	MEAN
		1.3955	2.3924	3.7563	5.0177	6.3635	7.0047	5.9654	5.6221	4.3048	2.9863	1.5550	0.9779	8.0992	SD
30	0	1.410	2.610	4.953	10.006	14.795	16.916	16.458	11.824	5.956	2.598	1.545	1.143	7.515	MOYEN
		0.5329	1.2317	1.9379	2.5415	4.1104	5.0820	4.1113	3.1902	1.8454	1.0913	0.5701	0.6243	6.4804	EC
60	0	1.427	2.591	3.998	5.584	8.811	10.560	9.688	6.310	3.733	2.343	1.461	1.121	4.798	MEAN
		0.4543	1.0626	1.4223	1.6659	2.1414	2.3388	2.0510	1.7460	1.4044	0.8556	0.5001	0.5571	3.5497	SD
90	0	1.450	2.564	3.730	4.719	6.796	7.787	7.321	5.095	3.200	2.058	1.348	1.091	3.926	MOYEN
		0.4957	1.0085	1.1961	1.0893	1.5622	1.6844	1.4763	1.1815	0.8970	0.6490	0.5024	0.5137	2.5465	EC
30	270	3.001	5.866	9.528	14.292	17.162	18.843	18.984	15.946	10.612	6.195	3.080	2.118	10.461	MEAN
		1.5868	2.6283	3.7312	4.8817	5.7336	6.4471	5.4829	5.2019	4.2125	3.0579	1.7493	1.0649	7.4414	SD
60	270	3.084	5.816	8.903	12.711	14.924	16.303	16.462	14.072	9.649	5.828	3.027	2.125	9.400	MOYEN
		1.8442	2.9005	3.8583	4.7636	5.3353	5.8579	5.1023	4.8521	4.1043	3.1407	1.9106	1.1941	6.5527	EC
90	270	2.895	5.222	7.560	10.224	11.732	12.636	12.807	11.087	7.795	4.850	2.676	1.973	7.614	MEAN
		1.8606	2.7899	3.5665	4.0580	4.3945	4.7088	4.1904	4.0197	3.5001	2.7786	1.8072	1.1956	5.1728	SD
30	225	4.987	8.337	12.025	16.692	18.672	19.821	20.354	17.983	12.924	8.473	4.635	3.640	12.369	MOYEN
		3.5155	4.5092	5.5149	6.2308	6.7095	7.0784	6.1738	6.3880	5.9331	4.9298	3.3503	2.5483	8.1007	EC
60	225	6.147	9.462	12.275	15.530	16.243	16.906	17.542	16.370	12.694	9.055	5.407	4.516	11.834	MEAN
		4.8559	5.7532	6.3042	6.3608	6.1199	6.1511	5.5070	6.0876	6.3733	5.8263	4.4078	3.6052	7.3146	SD
90	225	6.062	8.816	10.475	12.081	11.923	12.077	12.640	12.365	10.241	7.886	5.114	4.474	9.501	MOYEN
		4.9908	5.6474	5.7370	5.1514	4.4536	4.2395	3.8978	4.6181	5.3298	5.3481	4.3872	3.7531	5.6264	EC
30	180	5.896	9.369	13.150	17.782	19.316	20.030	20.745	18.579	13.797	9.470	5.310	4.331	13.138	MEAN
		4.4419	5.3795	6.4426	6.7844	7.1927	7.2928	6.4511	6.8888	6.6977	5.8360	4.0821	3.2729	8.4335	SD
60	180	7.717	11.211	13.975	16.758	16.581	16.522	17.433	16.783	13.847	10.693	6.570	5.712	12.804	MOYEN
		6.4507	7.2290	7.7030	6.8826	6.3485	5.9586	5.4490	6.4943	7.3854	7.2962	5.6726	4.8706	7.7428	EC
90	180	7.860	10.736	12.056	12.464	11.142	10.607	11.331	11.808	11.041	9.603	6.431	5.856	10.065	MEAN
		6.8090	7.2579	7.0470	5.1655	3.9441	3.3240	3.1554	4.4013	6.0928	6.8750	5.8177	5.2127	5.9878	SD
30	135	4.928	8.079	12.096	17.347	19.651	20.194	20.840	18.066	12.757	8.375	4.498	3.626	12.530	MOYEN
		3.5106	4.4595	5.8214	6.5789	7.5038	7.5597	6.7094	6.8693	6.1297	5.0481	3.2614	2.5680	8.5121	EC
60	135	6.046	9.025	12.402	16.553	17.713	17.468	18.288	16.522	12.454	8.895	5.171	4.492	12.077	MEAN
		4.8414	5.6609	6.7807	6.8664	7.1985	6.8271	6.2565	6.7987	6.6680	6.0156	4.2697	3.6378	7.8923	SD
90	135	5.945	8.339	10.608	13.071	13.233	12.548	13.274	12.506	10.000	7.720	4.846	4.447	9.703	MOYEN
		4.9744	5.5441	6.2141	5.6457	5.3948	4.8215	4.5375	5.2805	5.6327	5.5530	4.2436	3.7890	6.1066	EC
30	90	2.938	5.579	9.628	15.173	18.537	19.366	19.667	16.061	10.421	6.093	2.926	2.104	10.702	MEAN
		1.6054	2.6078	4.1103	5.3734	6.8694	7.1548	6.2669	5.8621	4.5306	3.1980	1.6363	1.0827	8.0253	SD
60	90	2.999	5.422	9.030	13.891	16.766	17.000	17.368	14.226	9.393	5.688	2.818	2.107	9.720	MOYEN
		1.8753	2.8630	4.3438	5.4400	6.7216	6.7895	6.0907	5.7129	4.5372	3.3334	1.7868	1.2149	7.3277	EC
90	90	2.811	4.844	7.653	11.218	13.230	13.182	13.515	11.188	7.516	4.704	2.482	1.954	7.853	MEAN
		1.8939	2.7403	3.9828	4.6777	5.5246	5.4920	5.0014	4.7650	3.8854	2.9657	1.7062	1.2112	5.8209	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

PRINCE GEORGE A (BC/CB) LATITUDE 53 DEG 53 MIN LONGITUDE 122 DEG 40 MIN PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	2.884	5.705	9.823	15.339	18.697	20.308	20.434	16.792	10.892	6.236	2.979	2.082	11.039	MEAN
	1.398	2.397	3.763	5.027	6.375	7.018	5.976	5.632	4.312	2.991	1.558	.980	8.096	S.D.
LATITUDE	7.473	11.017	14.035	17.260	17.412	17.494	18.396	17.447	14.081	10.631	6.422	5.524	13.092	MOYEN
	6.173	7.002	7.610	7.031	6.683	6.377	5.793	6.741	7.420	7.157	5.466	4.644	7.980	EC.T.
LAT.+15 DEG	7.946	11.319	13.685	15.786	15.151	14.898	15.796	15.575	13.295	10.612	6.681	5.893	12.211	MEAN
	6.754	7.453	7.725	6.560	5.762	5.260	4.862	6.033	7.218	7.387	5.887	5.124	7.300	S.D.
90 DEG.	7.861	10.737	12.057	12.466	11.144	10.609	11.333	11.809	11.042	9.605	6.432	5.857	10.070	MOYEN
	6.821	7.272	7.060	5.175	3.952	3.331	3.162	4.409	6.104	6.887	5.828	5.222	5.985	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	2.700	4.873	7.402	10.135	11.213	11.796	12.086	10.776	7.807	5.053	2.713	1.932	7.384	MEAN
	1.309	2.025	2.818	3.411	4.034	4.246	3.704	3.608	3.159	2.425	1.418	.891	4.713	S.D.
LATITUDE	6.858	9.152	10.592	12.099	11.695	11.605	12.375	12 206	10.332	8.419	5.681	5.314	9.689	MOYEN
	5.607	5.839	5.834	5.282	5.036	4.771	4.394	5.022	5.715	5.737	4.833	4.603	5.794	EC.T.
LAT.+15 DEG	7.277	9.365	10.320	11.202	10.439	10.177	10.932	11 105	9.801	8.366	5.890	5.681	9.207	MEAN
	6.122	6.201	5.923	5.007	4.514	4.142	3.868	4.626	5.592	5.901	5.189	5.073	5.554	S.D.
90 DEG.	7.181	8.836	9.075	9.000	7.865	7.401	8.033	8.628	8.197	7.521	5.645	5.653	7.747	MOYEN
	6.167	6.029	5.404	4.038	3.259	2.790	2.679	3.524	4.765	5.469	5.117	5.164	4.806	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	.940	.855	.753	.658	.596	.578	.588	642	.714	.808	.910	.944	.748	MEAN
	.071	.055	.058	.054	.056	.057	.054	.052	.063	.059	.067	.120	.150	S.D.
LATITUDE	.920	.828	.749	.690	.657	648	.661	.690	.721	.784	.883	.948	.765	MOYEN
	.073	.069	.067	.059	.063	.064	.059	.055	.073	.074	.075	.106	.125	EC.T.
LAT.+15 DEG	.918	.823	.748	.698	.672	.666	678	.702	.723	.780	.879	.949	.770	MEAN
	.075	.072	.069	.060	.066	.067	.062	.056	.074	.078	.077	.104	.120	S.D.
90 DEG.	.916	.818	.746	.709	.688	.680	694	.717	.727	.774	.875	.949	.775	MOYEN
	.076	.075	.069	.060	.069	.072	.065	.056	.074	.081	.080	.103	.117	EC.T.

EDMONTON INT'L. (ALTA) (3012205)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	3.922	7.278	12.234	17.251	20.684	21.433	21.967	18.796	12.886	8.087	4.252	2.821	12.654	MEAN
		1.5288	2.8198	4.4055	5.3493	6.0359	6.8883	5.9658	5.2662	4.8985	3.0649	1.8865	1.0820	8.3086	SD
30	0	1.694	3.052	5.806	10.893	15.975	17.744	17.427	12.616	6.515	2.631	1.628	1.262	8.126	MOYEN
		0.7371	1.3607	2.3226	2.8683	3.8647	4.9127	4.0493	3.0004	2.0649	1.1042	0.7405	0.4949	6.7813	EC
60	0	1.792	3.192	4.886	5.755	8.914	10.761	9.774	5.931	3.647	2.407	1.633	1.314	5.008	MEAN
		0.6576	1.1982	1.7450	1.8570	1.9816	2.1838	1.8431	1.4665	1.2949	0.8654	0.6494	0.4413	3.4843	SD
90	0	1.926	3.383	5.117	5.170	6.868	7.873	7.355	4.898	3.275	2.237	1.638	1.386	4.265	MOYEN
		0.6554	1.1699	1.7121	1.4858	1.3965	1.5519	1.2944	0.9320	0.8337	0.6434	0.6362	0.4489	2.4752	EC
30	270	4.136	7.552	12.304	16.400	19.252	19.864	20.481	18.071	12.567	8.034	4.393	2.939	12.183	MEAN
		1.7166	3.0209	4.4428	5.0092	5.5150	6.1231	5.4654	4.7440	4.7393	3.0564	1.9787	1.1926	7.6268	SD
60	270	4.325	7.642	11.904	14.831	16.933	17.183	17.799	16.142	11.531	7.651	4.440	3.054	11.131	MOYEN
		1.9670	3.2910	4.6200	4.7791	5.1085	5.4446	4.9865	4.3732	4.5141	3.0936	2.1410	1.3736	6.6637	EC
90	270	4.119	7.035	10.558	12.144	13.358	13.323	13.848	12.813	9.366	6.418	4.019	2.904	9.164	MEAN
		1.9606	3.1483	4.3477	4.1399	4.1767	4.3643	4.0295	3.6094	3.7930	2.7039	2.0298	1.3828	5.2379	SD
30	225	7.084	10.837	15.627	19.234	20.955	20.948	21.995	20.555	15.534	11.411	7.219	5.396	14.746	MOYEN
		3.6016	5.0631	6.4193	6.4634	6.4321	6.8416	6.1840	5.9001	6.5750	4.9562	4.0028	2.9349	8.1292	EC
60	225	8.871	12.456	16.505	18.243	18.404	17.842	19.006	18.961	15.427	12.417	8.705	6.897	14.481	MEAN
		4.9377	6.3054	7.3593	6.5428	5.8518	5.8422	5.4754	5.5773	6.9228	5.7895	5.2258	4.1288	7.2788	SD
90	225	8.815	11.768	14.627	14.437	13.509	12.655	13.594	14.363	12.497	10.895	8.346	6.922	11.864	MOYEN
		5.0597	6.0978	6.7697	5.3717	4.2303	3.9506	3.8136	4.2146	5.7107	5.2371	5.1574	4.2783	5.6507	EC
30	180	8.409	12.222	16.900	20.323	21.423	21.171	22.301	21.097	16.682	12.913	8.536	6.477	15.714	MEAN
		4.5248	6.0453	7.3888	7.1763	6.8473	7.2183	6.4723	6.4783	7.3893	5.9016	5.0321	3.7526	8.3992	SD
60	180	11.160	14.798	18.408	19.368	18.356	17.380	18.666	19.147	16.888	14.879	10.972	8.769	15.729	MOYEN
		6.5321	7.9619	8.8125	7.3394	6.0253	5.8917	5.4473	6.1136	8.0161	7.3122	6.9985	5.5421	7.7432	EC
90	180	11.437	14.317	16.356	14.559	12.129	10.952	11.905	13.326	13.443	13.458	10.907	9.084	12.641	MEAN
		6.8754	7.8783	8.1246	5.7181	3.6913	3.2357	3.1158	4.1562	6.5222	6.8026	7.1484	5.9029	6.2983	SD
30	135	6.949	10.510	15.215	19.541	21.506	21.403	22.315	20.278	15.382	11.310	7.140	5.303	14.751	MOYEN
		3.6020	5.0970	6.6473	7.0255	7.0697	7.5813	6.6956	6.5141	6.7358	5.1275	4.0994	2.9489	8.5014	EC
60	135	8.638	11.898	15.844	18.713	19.243	18.499	19.502	18.565	15.179	12.247	8.569	6.737	14.475	MEAN
		4.9251	6.3603	7.6767	7.3556	6.7371	6.8655	6.1726	6.4410	7.1789	6.0557	5.3865	4.1456	7.7909	SD
90	135	8.547	11.153	13.926	14.889	14.258	13.218	14.030	13.992	12.237	10.711	8.193	6.737	11.821	MOYEN
		5.0378	6.1533	7.0529	6.1407	4.9924	4.8136	4.4130	4.9789	5.9720	5.5153	5.3322	4.2914	6.0528	EC
30	90	3.984	7.167	11.799	16.811	20.025	20.514	20.941	17.704	12.371	7.914	4.303	2.838	12.216	MEAN
		1.7323	3.0515	4.7282	5.8089	6.3897	7.1907	6.2081	5.5881	4.9463	3.2672	2.0840	1.2167	8.1402	SD
60	90	4.124	7.128	11.216	15.388	17.967	18.061	18.435	15.651	11.269	7.489	4.320	2.917	11.177	MOYEN
		1.9674	3.3277	4.9086	5.8566	6.1854	6.8243	5.9366	5.4203	4.7942	3.3635	2.2670	1.3926	7.3375	EC
90	90	3.928	6.561	9.938	12.625	14.189	14.031	14.335	12.351	9.146	6.271	3.907	2.774	9.179	MEAN
		1.9540	3.1777	4.5362	5.0905	5.0459	5.4844	4.8052	4.4695	4.0469	2.9427	2.1289	1.3902	5.7857	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

EDMONTON INT'L A (ALTA/ALB) LATITUDE 53 DEG 19 MIN LONGITUDE 113 DEG 35 MIN PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	3.922	7.278	12.234	17.251	20.684	21.433	21.967	18.796	12.886	8.087	4.252	2.821	12.659	MEAN
	1.531	2.825	4.413	5.359	6.047	6.901	5.977	5.276	4.907	3.070	1.890	1.084	8.304	S.D.
LATITUDE	10.745	14.478	18.382	19.945	19.380	18.524	19.821	19.967	17.172	14.730	10.633	8.416	16.021	MOYEN
	6.225	7.710	8.687	7.481	6.376	6.345	5.826	6.359	8.076	7.170	6.717	5.264	7.965	EC.T.
LAT.+15 DEG	11.501	14.982	18.191	18.376	16.832	15.730	16.972	17.843	16.276	14.825	11.217	9.069	15.150	MEAN
	6.819	8.165	8.852	7.066	5.496	5.238	4.891	5.717	7.821	7.381	7.246	5.807	7.391	S.D.
90 DEG.	11.437	14.317	16.358	14.561	12.129	10.952	11.906	13.326	13.443	13.459	10.908	9.084	12.646	MOYEN
	6.886	7.893	8.138	5.729	3.698	3.241	3.121	4.163	6.533	6.814	7.161	5.913	6.292	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	3.721	6.242	9.279	11.425	12.380	12.378	12.999	12.003	9.150	6.549	3.894	2.761	8.575	MEAN
	1.416	2.316	3.320	3.634	3.811	4.215	3.746	3.419	3.472	2.398	1.682	1.055	4.744	S.D.
LATITUDE	9.870	11.943	13.965	14.064	13.106	12.356	13.468	14.033	12.508	11.605	9.323	8.177	12.035	MOYEN
	5.650	6.260	6.740	5.612	4.814	4.773	4.454	4.786	6.073	5.637	5.860	5.105	5.822	EC.T.
LAT.+15 DEG	10.534	12.298	13.812	13.116	11.702	10.828	11.888	12.807	11.914	11.623	9.790	8.805	11.590	MEAN
	6.181	6.617	6.875	5.370	4.314	4.142	3.917	4.420	5.922	5.791	6.309	5.629	5.693	S.D.
90 DEG.	10.442	11.681	12.398	10.567	8.672	7.722	8.563	9.835	9.916	10.473	9.466	8.812	9.871	MOYEN
	6.231	6.376	6.320	4.417	3.060	2.727	2.658	3.353	4.990	5.321	6.215	5.728	5.136	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	.952	.863	.759	.661	.597	.574	.589	.638	.711	.813	.920	.980	.754	MEAN
	.027	.042	.045	.048	.044	.046	.042	.047	.043	.042	.033	.025	.148	S.D.
LATITUDE	.922	.830	.754	.696	.666	.653	.669	.695	.721	.788	.881	.972	.770	MOYEN
	.049	.058	.054	.054	.048	.056	.050	.049	.051	.054	.058	.022	.116	EC.T.
LAT.+15 DEG	.919	.825	.753	.704	.684	.673	.688	.709	.724	.783	.876	.971	.776	MEAN
	.052	.062	.056	.055	.050	.060	.053	.049	.052	.057	.063	.022	.110	S.D.
90 DEG.	.915	.820	.751	.715	.702	.689	.707	.728	.728	.777	.871	.970	.781	MOYEN
	.055	.065	.056	.055	.053	.065	.057	.050	.052	.061	.067	.023	.105	EC.T.

REGINA A (SASK) (4016560)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZN	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	5.136	8.898	13.757	17.337	21.521	22.681	23.900	20.522	14.408	9.079	5.197	3.991	13.890	MEAN
		1.8377	3.0318	4.8353	6.0279	6.5476	6.4728	5.5602	5.5013	5.1027	3.6824	2.2143	1.4886	8.4661	SD
30	0	2.026	3.293	6.537	11.413	16.797	19.187	19.176	14.136	7.549	3.271	2.077	1.617	8.949	MOYEN
		0.9351	1.7357	2.5863	3.0076	4.2310	4.6700	3.8402	3.2415	2.2439	1.4749	0.9022	0.6964	7.1893	EC
60	0	2.201	3.609	4.976	5.869	9.180	12.059	10.672	6.321	3.753	2.821	2.088	1.735	5.447	MEAN
		0.7957	1.4475	2.0910	2.0900	2.0149	2.1642	1.9475	1.7774	1.5700	1.1737	0.7563	0.5752	3.7303	SD
90	0	2.439	4.054	5.434	5.222	6.792	8.350	7.482	5.124	3.421	2.617	2.103	1.896	4.580	MOYEN
		0.7563	1.2844	2.0310	1.5783	1.3134	1.4775	1.2371	1.0955	0.9388	0.8482	0.7109	0.5436	2.4205	EC
30	270	5.318	9.023	13.631	16.408	19.744	21.248	22.342	19.467	13.817	8.938	5.254	4.201	13.299	MEAN
		1.9891	3.1648	4.8830	5.7058	6.0213	5.8525	5.2470	5.0287	4.9492	3.6556	2.2339	1.6485	7.7818	SD
60	270	5.480	9.061	13.102	14.670	17.013	18.442	19.412	17.216	12.456	8.376	5.205	4.390	12.079	MOYEN
		2.2355	3.4549	4.9871	5.3981	5.4429	5.2596	4.8224	4.6164	4.7281	3.6329	2.3790	1.9025	6.7486	EC
90	270	5.182	8.392	11.658	11.894	13.228	14.322	15.095	13.588	10.006	6.951	4.669	4.180	9.935	MEAN
		2.2088	3.3231	4.6817	4.5417	4.3053	4.1779	3.8201	3.7623	3.9506	3.1498	2.2278	1.9064	5.2504	SD
30	225	8.801	13.030	17.305	18.987	21.441	22.045	23.736	21.973	17.005	12.251	8.161	7.275	16.011	MOYEN
		4.1130	5.3187	6.9497	7.3038	6.9368	6.4194	5.7925	6.1234	6.7638	5.8779	4.4477	3.8032	8.2235	EC
60	225	10.764	14.829	18.063	17.715	18.460	18.604	20.275	19.699	16.586	13.011	9.510	9.118	15.569	MEAN
		5.5424	6.6048	7.8630	7.2755	6.1938	5.4354	5.0884	5.7182	7.0867	6.7713	5.6719	5.2521	7.3760	SD
90	225	10.552	13.923	15.836	13.839	13.285	13.078	14.304	14.839	13.189	11.222	8.957	9.042	12.663	MOYEN
		5.6133	6.3726	7.1312	5.7709	4.3417	3.5812	3.4631	4.2294	5.7938	6.0384	5.5111	5.3696	5.7905	EC
30	180	10.434	14.794	18.811	19.978	21.999	22.001	23.844	22.622	18.324	13.729	9.518	8.685	17.068	MEAN
		5.1517	6.4004	7.9156	8.0195	7.2559	6.6630	5.9169	6.6220	7.5693	6.9600	5.5914	4.8471	8.4667	SD
60	180	13.590	17.812	20.280	18.676	18.513	17.679	19.483	20.094	18.249	15.401	11.853	11.559	16.924	MOYEN
		7.3351	8.4136	9.2817	7.9679	6.1831	5.2493	4.7997	6.0882	8.0856	8.5086	7.6288	7.0474	7.9102	EC
90	180	13.758	17.144	17.772	13.746	11.876	10.768	11.862	13.538	14.199	13.648	11.575	11.846	13.456	MEAN
		7.6381	8.2997	8.4121	5.8568	3.5627	2.6137	2.4984	3.9509	6.4229	7.7961	7.6802	7.4200	6.7084	SD
30	135	8.752	12.863	17.098	19.264	22.241	22.286	23.956	22.009	17.066	12.168	8.112	7.181	16.095	MOYEN
		4 1458	5.4722	7.1005	7.7925	7.4224	7.0514	6.0974	6.6713	6.9721	6.0237	4.6438	3.8512	8.5544	EC
60	135	10.679	14.548	17.751	18.153	19.662	19.001	20.651	19.984	16.679	12.868	9.426	8.955	15.698	MEAN
		5.5785	6.8324	8.0771	7.9637	6.8622	6.2867	5.5158	6.4822	7.3827	7.0039	5.9847	5.3154	7.8301	SD
90	135	10.455	13.623	15.519	14.248	14.342	13.412	14.639	14.907	13.285	11.059	8.865	8.855	12.760	MOYEN
		5.6484	6.6113	7.3529	6.4104	4.9278	4.2985	3.8561	4.9169	6.0710	6.2851	5.8451	5.4352	6.1496	EC
30	90	5.268	8.840	13.394	16.791	20.860	21.573	22.631	19.527	13.891	8.825	5.212	4.103	13.428	MEAN
		2.0700	3.3851	5.0951	6.3968	6.7285	6.7932	5.7243	5.7884	5.2276	3.8463	2.4762	1.7449	8.2384	SD
60	90	5.409	8.816	12.763	15.177	18.515	18.893	19.820	17.289	12.568	8.226	5.143	4.258	12.253	MOYEN
		2.3264	3.7066	5.2639	6.2744	6.3501	6.4794	5.4985	5.5636	5.0674	3.8876	2.6758	2.0148	7.3567	EC
90	90	5.113	8.147	11.310	12.314	14.441	14.623	15.336	13.599	10.122	6.833	4.600	4.048	10.046	MEAN
		2.2892	3.5376	4.9081	5.2851	5.0826	5.2135	4.4584	4.5540	4.2368	3.3757	2.4918	2.0019	5.7485	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

REGINA A (SASK) LATITUDE 50 DEG 26 MIN LONGITUDE 104 DEG 40 MIN PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0 DEG.	5.136	8.898	13.757	17.337	21.521	22.681	23.900	20.522	14.408	9.079	5.197	3.991	13.894	MEAN
	1.841	3.037	4.843	6.039	6.560	6.485	5.571	5.512	5.112	3.689	2.218	1.491	8.461	S.D.
LATITUDE	12.883	17.232	20.248	19.532	20.075	19.460	21.362	21.421	18.730	15.238	11.376	10.901	17.374	MOYEN
	6.834	7.999	9.098	8.243	6.749	5.894	5.337	6.470	8.177	8.265	7.190	6.535	8.172	EC.T.
LAT.+15 DEG	13.856	17.975	20.118	18.021	17.460	16.516	18.236	19.144	17.793	15.338	12.005	11.816	16.517	MEAN
	7.553	8.576	9.308	7.737	5.799	4.829	4.445	5.812	7.956	8.566	7.807	7.273	7.723	S.D.
90 DEG.	13.759	17.146	17.775	13.749	11.878	10.769	11.864	13.540	14.200	13.650	11.577	11.846	13.462	MOYEN
	7.651	8.316	8.427	5.868	3.569	2.619	2.503	3.958	6.435	7.810	7.694	7.433	6.702	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0 DEG.	4.755	7.526	10.331	11.646	13.160	13.256	14.269	13.192	10.242	7.256	4.660	3.794	9.517	MEAN
	1.683	2.497	3.624	4.132	4.240	4.076	3.503	3.627	3.629	2.886	1.954	1.410	4.870	S.D.
LATITUDE	11.406	14.094	15.210	13.833	13.709	13.018	14.591	15.035	13.634	11.855	9.749	9.904	13.000	MOYEN
	6.023	6.487	7.034	6.188	5.135	4.521	4.066	4.905	6.162	6.456	6.155	5.911	6.074	EC.T.
LAT.+15 DEG	12.211	14.630	15.101	12.917	12.252	11.423	12.884	13.733	13.019	11.869	10.229	10.690	12.572	MEAN
	6.635	6.936	7.205	5.902	4.588	3.907	3.561	4.529	6.038	6.672	6.661	6.559	6.041	S.D.
90 DEG.	12.055	13.859	13.315	10.043	8.594	7.681	8.699	10.041	10.486	10.464	9.787	10.662	10.460	MOYEN
	6.688	6.694	6.519	4.585	3.002	2.307	2.183	3.228	4.931	6.042	6.528	6.675	5.518	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0 DEG.	.926	.848	.751	.670	.608	.582	.596	.642	.711	.802	.899	.951	.748	MEAN
	.027	.041	.045	.047	.047	.047	.037	.043	.045	.044	.032	.017	.135	S.D.
LATITUDE	.885	.819	.745	.698	.671	.658	.677	.694	.721	.776	.860	.912	.759	MOYEN
	.052	.064	.056	.053	.054	.052	.039	.046	.050	.062	.057	.048	.101	EC.T.
LAT.+15 DEG	.880	.815	.743	.705	.688	.679	.699	.709	.723	.771	.855	.908	.764	MEAN
	.056	.067	.057	.054	.056	.055	.040	.047	.050	.066	.061	.052	.095	S.D.
90 DEG.	.875	.809	.741	.717	.709	.701	.725	.732	.729	.764	.848	.903	.771	MOYEN
	.060	.071	.058	.054	.059	.060	.045	.046	.050	.071	.066	.056	.089	EC.T.

WINNIPEG INT'L. A (MAN) (5023222)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	5.214	8.969	13.917	17.307	20.734	22.134	22.609	19.104	13.376	7.685	4.596	3.917	13.315	MEAN
		1.5788	2.6898	4.4253	6.4765	7.5634	7.5029	6.2788	5.8412	4.9561	3.5938	2.0396	1.3705	8.4467	SD
30	0	1.903	3.060	6.655	11.259	16.150	18.689	18.348	13.429	7.206	2.886	2.047	1.554	8.513	MOYEN
		0.9575	1.6761	2.4028	3.3271	5.0821	5.7089	4.4674	3.5108	2.2517	1.2064	0.8838	0.7086	7.0910	EC
60	0	2.131	3.455	4.979	5.509	8.603	11.461	10.305	6.123	3.569	2.419	2.034	1.690	5.140	MEAN
		0.6950	1.2230	1.9592	2.1133	2.3793	2.7995	2.1849	1.9153	1.4687	0.9077	0.7156	0.5263	3.6110	SD
90	0	2.442	4.019	5.586	5.063	6.311	7 782	7.132	4.914	3.229	2.186	2.016	1.875	4.351	MOYEN
		0.4885	0.8611	1.6125	1.7485	1.6398	1.8103	1.3999	1.2461	0.9423	0.6588	0.6596	0.4321	2.3174	EC
30	270	5.461	9.109	13.768	16.395	19.325	20.602	21.173	18.058	12.616	7.422	4.588	4.091	12.638	MEAN
		1.8377	2.9255	4.6801	6.3233	7.2621	7.1186	5.8573	5.5744	4.8347	3.5341	2.1497	1.5813	7.8440	SD
60	270	5.684	9.254	13.291	14.592	16.704	17.613	18.210	15.875	11.226	6.855	4.484	4.259	11.440	MOYEN
		2.1657	3.3093	4.9910	6.0780	6.5911	6.4136	5.2914	5.1162	4.6135	3.4495	2.3139	1.8804	6.8383	EC
90	270	5.417	8.661	11.933	11.875	12.917	13.525	14.007	12.482	8.974	5.625	4.007	4.066	9.412	MEAN
		2.1604	3.2448	4.7890	5.2164	5.2211	5.0742	4.1735	4.0699	3.8371	2.9445	2.2014	1.9128	5.3648	SD
30	225	9.077	13.216	17.439	19.158	20.958	21.560	22.531	20.345	15.541	10.119	6.919	7.064	15.257	MOYEN
		4.0783	5.2315	6.6735	7.8708	8.1212	7.5918	6.3870	6.5544	6.4317	5.5572	4.2633	3.8174	8.3653	EC
60	225	11.163	15.095	18.228	17.879	18.134	18.024	19.138	18.290	14.954	10.591	7.927	8.818	14.808	MEAN
		5.6191	6.6480	7.7153	7.9179	7.2864	6.4577	5.5290	6.1543	6.6475	6.2812	5.5011	5.3306	7.6049	SD
90	225	10.978	14.227	16.060	13.959	13.037	12.516	13.424	13.582	11.773	9.014	7.420	8.736	12.040	MOYEN
		5.7149	6.4592	7.1019	6.4558	5.1613	4.3531	3.7634	4.5631	5.4058	5.5276	5.3934	5.4676	6.0637	EC
30	180	10.735	15.095	19.000	20.290	21.353	21.726	22.726	21.057	16.880	11.392	8.028	8.469	16.332	MEAN
		5.1723	6.3730	7.5867	8.4212	8.2278	7.6673	6.5197	6.8395	7.1402	6.5781	5.2904	4.9099	8.6012	SD
60	180	14.033	18.253	20.488	19.056	17.931	17.410	18.531	18.599	16.698	12.649	9.843	11.252	16.197	MOYEN
		7.5106	8.5523	9.0341	8.4107	6.9519	6.0195	5.2706	6.2317	7.5053	7.9255	7.2730	7.2140	8.1141	EC
90	180	14.227	17.598	17.984	14.052	11.410	10.451	11.261	12.471	12.905	11.103	9.561	11.522	12.880	MEAN
		7.8465	8.4714	8.2211	6.3805	4.0435	3.0972	2.8245	4.0371	5.8918	7.1927	7.3639	7.6139	6.9056	SD
30	135	8.941	13.172	17.372	19.583	21.358	22.089	22.853	20.650	15.907	10.215	6.939	7.049	15.437	MOYEN
		4.0879	5.3467	6.7620	7.9353	8.1836	7.8855	6.6957	6.6529	6.6196	5.7625	4.3010	3.8705	8.5750	EC
60	135	10.926	15.014	18.122	18.543	18.710	18.810	19.620	18.757	15.545	10.749	7.961	8.792	15.079	MEAN
		5.6395	6.8324	7.8830	8.0046	7.3878	6.8651	5.9492	6.3012	6.9080	6.6263	5.5622	5.4176	7.8777	SD
90	135	10.713	14.134	15.951	14.591	13.515	13.161	13.839	14.002	12.364	9.182	7.458	8.706	12.277	MOYEN
		5.7397	6.6439	7.2704	6.5126	5.2576	4.6562	4.1189	4.7020	5.6338	5.8945	5.4512	5.5654	6.2491	EC
30	90	5.328	9.057	13.693	16.971	19.887	21.352	21.630	18.480	13.104	7.538	4.621	4.084	12.895	MEAN
		1.8396	3.0368	4.6997	6.3923	7.3559	7.5163	6.2670	5.6964	5.0445	3.7410	2.1829	1.6523	8.1350	SD
60	90	5.492	9.192	13.187	15.369	17.430	18.622	18.835	16.439	11.875	7.012	4.526	4.247	11.782	MOYEN
		2.1799	3.4631	5.0276	6.1475	6.7561	6.8998	5.8242	5.3179	4.8416	3.7263	2.3629	1.9755	7.2114	EC
90	90	5.224	8.600	11.833	12.515	13.533	14.316	14.503	12.952	9.517	5.768	4.036	4.044	9.686	MEAN
		2.1829	3.3948	4.8321	5.2498	5.3936	5.4358	4.6624	4.3019	4.0341	3.1948	2.2331	2.0014	5.6592	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

WINNIPEG INT'L A (MAN)　　LATITUDE 49 DEG 54 MIN　　LONGITUDE 97 DEG 14 MIN　　PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	5.214	8.969	13.917	17.307	20.734	22.134	22.609	19.104	13.376	7.685	4.596	3.917	13.320	MEAN
	1.582	2.695	4.433	6.488	7.577	7.517	6.291	5.852	4.965	3.600	2.043	1.373	8.442	S.D.
LATITUDE	13.242	17.594	20.436	19.940	19.540	19.287	20.387	19.918	17.186	12.538	9.454	10.580	16.636	MOYEN
	6.936	8.066	8.806	8.676	7.630	6.788	5.899	6.652	7.622	7.708	6.811	6.631	8.369	EC.T.
LAT.+15 DEG	14.290	18.416	20.348	18.467	17.002	16.361	17.432	17.796	16.309	12.587	9.946	11.488	15.849	MEAN
	7.725	8.718	9.073	8.217	6.563	5.597	4.941	5.974	7.385	7.963	7.437	7.421	7.947	S.D.
90 DEG.	14.227	17.598	17.986	14.054	11.411	10.452	11.246	12.472	12.905	11.104	9.562	11.532	12.884	MOYEN
	7.860	8.487	8.236	6.392	4.051	3.103	2.838	4.044	5.902	7.204	7.376	7.616	6.899	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	4.744	7.464	10.435	11.752	12.985	13.361	13.919	12.366	9.598	6.154	4.083	3.659	9.219	MEAN
	1.415	2.154	3.175	4.461	4.913	4.772	4.094	4.025	3.611	2.870	1.808	1.289	5.039	S.D.
LATITUDE	11.551	14.073	15.269	14.287	13.600	13.212	14.144	14.018	12.584	9.757	8.104	9.464	12.488	MOYEN
	6.017	6.406	6.599	6.464	5.751	5.142	4.533	5.110	5.817	6.071	5.842	5.908	6.227	EC.T.
LAT.+15 DEG	12.409	14.647	15.188	13.394	12.163	11.589	12.494	12.798	11.997	9.740	8.484	10.232	12.087	MEAN
	6.679	6.904	6.816	6.208	5.137	4.459	3.975	4.708	5.675	6.248	6.357	6.589	6.175	S.D.
90 DEG.	12.278	13.884	13.397	10.394	8.444	7.666	8.373	9.281	9.580	8.508	8.097	10.214	10.019	MOYEN
	6.757	6.680	6.188	4.922	3.355	2.681	2.459	3.329	4.581	5.607	6.270	6.727	5.590	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	.911	.835	.754	.676	.623	.599	.612	.641	.716	.801	.887	.933	.749	MEAN
	.023	.035	.041	.053	.058	.061	.059	.062	.065	.054	.035	.015	.127	S.D.
LATITUDE	.875	.802	.748	.706	.682	.670	.684	.692	.723	.774	.858	.897	.760	MOYEN
	.044	.054	.050	.055	.062	.067	.060	.063	.073	.073	.057	.039	.098	EC.T.
LAT.+15 DEG	.871	.797	.746	.713	.699	.691	.705	.706	.725	.769	.854	.893	.765	MEAN
	.048	.057	.052	.056	.064	.071	.061	.064	.074	.078	.062	.042	.093	S.D.
90 DEG.	.865	.791	.745	.726	.722	.715	.733	.730	.731	.761	.848	.888	.772	MOYEN
	.052	.060	.053	.056	.067	.078	.064	.064	.074	.083	.068	.047	.088	EC.T.

TORONTO (ONT) (6158350)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	5.136	7.861	11.551	17.061	18.734	20.896	21.471	18.862	13.721	8.766	4.473	3.769	12.708	MEAN
		2.5516	3.8249	6.1399	6.9977	7.9970	7.2664	6.6039	5.8355	5.5483	4.2580	2.7705	2.3389	8.4231	SD
30	0	2.045	3.105	6.530	12.036	15.418	18.026	18.044	14.175	8.434	3.938	2.158	1.676	8.819	MOYEN
		0.9222	1.3461	2.8036	4.2485	5.9203	5.6450	5.0423	3.9352	2.9932	1.6928	1.0402	0.8108	7.0961	EC
60	0	2.148	2.971	3.915	5.511	9.139	11.512	10.858	6.902	3.692	2.627	1.962	1.683	5.245	MEAN
		0.8082	1.1009	1.7152	2.3161	2.8323	2.8138	2.4834	2.1842	1.4507	1.2378	0.9100	0.7721	3.8635	SD
90	0	2.289	3.275	4.043	4.594	5.826	6.812	6.418	4.978	3.301	2.353	1.707	1.694	3.944	MOYEN
		0.9143	1.2610	1.7768	1.6660	1.6738	1.5688	1.3902	1.3037	1.0165	0.9027	0.8188	0.8637	2.1590	EC
30	270	5.053	7.710	11.047	15.859	17.533	19.480	19.880	17.671	13.096	8.373	4.282	3.707	11.996	MEAN
		2.6641	3.8891	5.9979	6.5750	7.4758	6.7521	6.0493	5.4958	5.3079	4.1811	2.7790	2.3931	7.8295	SD
60	270	4.900	7.376	10.059	13.573	14.797	16.200	16.505	15.080	11.460	7.396	3.925	3.557	10.419	MOYEN
		2.7959	3.9878	5.6837	5.8920	6.4368	5.7839	5.1404	4.8863	4.8078	3.8799	2.7049	2.4642	6.6390	EC
90	270	4.408	6.598	8.505	10.540	11.125	12.032	12.289	11.531	8.952	5.840	3.238	3.153	8.195	MEAN
		2.6489	3.7590	5.0088	4.6964	4.8624	4.3388	3.8380	3.8021	3.8027	3.1524	2.3382	2.3068	5.0443	SD
30	225	7.510	10.493	13.445	17.965	18.489	20.086	20.835	19.370	15.436	10.866	5.832	5.531	13.844	MOYEN
		4.7248	6.0610	7.9236	7.8168	8.0962	7.0759	6.4667	6.2503	6.5867	5.9822	4.4586	4.3739	8.4271	EC
60	225	8.511	11.307	13.233	15.956	15.499	16.338	17.044	16.770	14.391	10.858	6.115	6.276	12.709	MEAN
		5.8827	7.0877	8.2527	7.2547	6.8167	5.7307	5.2717	5.5706	6.3970	6.4168	5.1389	5.4427	7.4194	SD
90	225	7.902	10.141	10.948	11.778	10.730	10.990	11.479	11.973	10.981	8.796	5.284	5.823	9.745	MOYEN
		5.6841	6.5998	7.0086	5.4125	4.4865	3.5979	3.3551	3.9263	4.9322	5.3884	4.6620	5.2480	5.5826	EC
30	180	8.612	11.757	14.482	18.874	18.606	20.027	20.987	19.884	16.334	11.978	6.597	6.362	14.564	MEAN
		5.6479	7.0735	8.7703	8.3309	8.1785	7.0576	6.5569	6.5120	7.1298	6.7922	5.2896	5.2991	8.6754	SD
60	180	10.412	13.394	14.666	16.746	14.922	15.387	16.346	16.786	15.386	12.615	7.417	7.716	13.497	MOYEN
		7.4656	8.7242	9.4109	7.6052	6.3743	5.1342	4.8962	5.5455	6.9290	7.6636	6.5461	7.0380	7.7479	EC
90	180	10.037	12.320	12.005	11.396	8.934	8.736	9.279	10.604	11.203	10.504	6.707	7.457	9.935	MEAN
		7.4553	8.2848	7.8763	5.0463	3.2490	2.2761	2.2915	3.2538	4.9932	6.5683	6.1937	7.0479	6.0014	SD
30	135	7.461	10.495	13.501	18.413	18.568	20.189	21.180	19.549	15.363	10.832	5.944	5.505	13.939	MOYEN
		4.6769	6.1481	8.0551	8.0963	8.2576	7.2556	6.7508	6.4863	6.7756	5.9949	4.5811	4.3833	8.5990	EC
60	135	8.427	11.312	13.324	16.669	15.615	16.512	17.570	17.064	14.275	10.803	6.307	6.232	12.860	MEAN
		5.8018	7.2069	8.4748	7.6282	7.0705	5.9814	5.6878	5.9018	6.6591	6.4174	5.3410	5.4522	7.6605	SD
90	135	7.811	10.149	11.039	12.447	10.845	11.123	11.926	12.227	10.859	8.745	5.499	5.773	9.879	MOYEN
		5.6056	6.7186	7.2671	5.7515	4.7572	3.7904	3.7333	4.2242	5.1916	5.3815	4.8844	5.2566	5.7843	EC
30	90	5.010	7.739	11.131	16.477	17.648	19.620	20.375	17.918	13.007	8.337	4.423	3.682	12.136	MEAN
		2.6323	4.0413	6.1989	6.9691	7.7211	7.0045	6.4639	5.8318	5.5812	4.2133	2.9388	2.4182	8.0780	SD
60	90	4.843	7.413	10.181	14.423	14.971	16.397	17.204	15.416	11.339	7.353	4.115	3.528	10.616	MOYEN
		2.7731	4.1774	6.0150	6.3827	6.8245	6.1138	5.7307	5.3353	5.1882	3.9336	2.9213	2.4869	6.9899	EC
90	90	4.340	6.592	8.592	11.213	11.279	12.155	12.821	11.778	8.833	5.785	3.399	3.116	8.337	MEAN
		2.6351	3.9051	5.3467	5.1367	5.2425	4.5804	4.3777	4.1989	4.1602	3.2127	2.5399	2.3163	5.3501	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

TORONTO (ONT) LATITUDE 43 DEG 40 MIN LONGITUDE 79 DEG 23 MIN PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	5.136	7.861	11.551	17.061	18.734	20.896	21.471	18.862	13.721	8.766	4.473	3.769	12.713	MEAN
	2.556	3.832	6.150	7.010	8.011	7.280	6.616	5.846	5.558	4.265	2.775	2.343	8.419	S.D.
LATITUDE	9.684	12.828	14.935	18.377	17.356	18.352	19.355	18.961	16.359	12.616	7.156	7.165	14.455	MOYEN
	6.691	8.081	9.351	8.276	7.603	6.404	6.008	6.288	7.274	7.440	6.058	6.295	8.393	EC.T.
LAT.+15 DEG	10.377	13.378	14.721	16.919	15.161	15.663	16.630	17.004	15.517	12.647	7.413	7.689	13.614	MEAN
	7.433	8.709	9.445	7.694	6.495	5.262	5.010	5.632	6.981	7.679	6.535	7.007	7.805	S.D.
90 DEG.	10.037	12.320	12.005	11.397	8.938	8.735	9.279	10.603	11.209	10.503	6.707	7.457	9.940	MOYEN
	7.467	8.300	7.890	5.055	3.250	2.280	2.295	3.259	4.994	6.579	6.205	7.060	5.996	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	4.518	6.471	8.688	11.859	12.309	13.432	13.904	12.805	9.975	6.998	3.836	3.394	9.026	MEAN
	2.266	3.147	4.646	4.946	5.387	4.870	4.493	4.015	4.051	3.415	2.395	2.125	5.445	S.D.
LATITUDE	8.240	10.194	11.206	13.296	12.302	12.932	13.717	13.662	12.045	9.846	5.848	6.221	10.811	MOYEN
	5.736	6.438	7.091	6.188	5.735	4.889	4.604	4.719	5.512	5.858	4.979	5.450	6.229	EC.T.
LAT.+15 DEG	8.780	10.554	11.031	12.393	11.019	11.387	12.147	12.492	11.477	9.814	6.002	6.636	10.326	MEAN
	6.343	6.895	7.156	5.840	5.093	4.216	4.021	4.341	5.335	6.018	5.332	6.033	5.988	S.D.
90 DEG.	8.409	9.590	8.959	8.574	6.769	6.581	7.089	8.110	8.397	8.045	5.336	6.371	7.692	MOYEN
	6.318	6.488	5.947	3.953	2.771	2.005	2.041	2.664	3.881	5.093	4.994	6.019	4.773	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	.876	.821	.748	.690	.650	.638	.642	.678	.723	.795	.852	.894	.750	MEAN
	.046	.051	.060	.068	.066	.062	.062	.054	.059	.056	.049	.033	.106	S.D.
LATITUDE	.847	.793	.743	.712	.692	.693	.698	.715	.727	.775	.818	.869	.757	MOYEN
	.066	.068	.066	.070	.070	.062	.064	.052	.065	.066	.074	.053	.088	EC.T.
LAT.+15 DEG	.841	.787	.741	.720	.707	.713	.718	.728	.729	.770	.811	.865	.761	MEAN
	.071	.072	.068	.070	.072	.064	.066	.052	.066	.069	.081	.058	.085	S.D.
90 DEG.	.832	.778	.738	.738	.736	.741	.752	.757	.737	.760	.798	.858	.769	MOYEN
	.078	.077	.068	.067	.078	.073	.073	.053	.067	.074	.092	.065	.082	EC.T.

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

SAULT STE. MARIE A (ONT) LATITUDE 46 DEG 29 MIN LONGITUDE 84 DEG 30 MIN PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0 DEG	4.740	8.812	13.719	17.780	20.851	21.016	21.600	18.601	12.964	7.837	4.383	3.778	13.027	MEAN
	2.359	3.865	5.740	7.507	8.189	8.105	6.978	6.402	5.427	3.857	2.287	2.048	8.731	S.D.
LATITUDE	8.843	14.873	18.739	19.477	19.345	18.262	19.269	18.863	15.468	11.119	7.183	7.514	14.911	MOYEN
	6.795	9.016	9.637	9.368	7.941	7.078	6.390	7.068	7.702	7.295	5.933	6.585	8.981	EC.T.
LAT.+15 DEG	9.387	15.482	18.590	17.978	16.863	15.585	16.543	16.899	14.624	11.044	7.416	8.039	14.028	MEAN
	7.513	9.714	9.838	8.763	6.770	5.792	5.321	6.329	7.434	7.527	6.449	7.344	8.415	S.D.
90 DEG.	9.125	14.520	15.882	12.877	10.523	9.324	9.934	11.173	11.022	9.339	6.832	7.887	10.682	MOYEN
	7.562	9.351	8.633	6.231	3.636	2.754	2.639	3.928	5.604	6.605	6.277	7.488	6.726	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0 DEG.	4.282	7.306	10.263	12.002	13.131	12.943	13.389	12.239	9.248	6.223	3.857	3.479	9.038	MEAN
	2.127	3.181	4.306	5.214	5.310	5.089	4.535	4.295	3.872	3.036	2.007	1.894	5.391	S.D.
LATITUDE	7.762	11.963	14.038	13.779	13.360	12.485	13.251	13.313	11.231	8.649	6.118	6.664	11.046	MOYEN
	5.905	7.205	7.307	7.007	5.948	5.272	4.855	5.287	5.743	5.691	5.026	5.806	6.590	EC.T.
LAT.+15 DEG	8.203	12.384	13.918	12.873	11.951	10.975	11.721	12.164	10.670	8.548	6.279	7.093	10.556	MEAN
	6.501	7.724	7.459	6.656	5.291	4.553	4.240	4.867	5.588	5.851	5.439	6.446	6.404	S.D.
90 DEG.	7.920	11.508	11.857	9.414	7.722	6.760	7.304	8.316	8.128	7.154	5.728	6.906	8.210	MOYEN
	6.497	7.368	6.530	4.845	3.087	2.382	2.305	3.189	4.273	5.086	5.253	6.526	5.341	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0 DEG.	.903	.829	.747	.670	.625	.613	.616	.656	.713	.795	.880	.919	.747	MEAN
	.037	.044	.048	.049	.053	.053	.051	.051	.051	.044	.039	.030	.120	S.D.
LATITUDE	.883	.806	.745	.693	.675	.670	.676	.696	.720	.778	.856	.891	.757	MOYEN
	.053	.062	.056	.057	.062	.058	.057	.055	.058	.058	.060	.060	.099	EC.T.
LAT.+15 DEG	.880	.802	.744	.700	.690	.688	.695	.708	.722	.774	.851	.887	.762	MEAN
	.056	.066	.058	.059	.065	.061	.058	.056	.060	.061	.065	.066	.095	S.D.
90 DEG.	.875	.795	.742	.713	.714	.709	.722	.731	.729	.767	.844	.881	.768	MOYEN
	.061	.070	.058	.061	.072	.069	.063	.056	.059	.066	.072	.074	.090	EC.T.

SAULT STE. MARIE A (ONT) (6057592)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	4.740	8.812	13.719	17.780	20.851	21.016	21.600	18.601	12.964	7.837	4.383	3.778	13.022	MEAN
		2.3545	3.8580	5.7302	7.4940	8.1749	8.0907	6.9657	6.3907	5.4174	3.8509	2.2827	2.0444	8.7351	SD
30	0	2.402	3.721	7.368	12.159	16.592	17.779	17.707	13.569	7.940	3.878	2.326	1.934	8.971	MOYEN
		0.8848	1.6218	2.4903	4.0128	5.6792	6.1860	5.1020	3.9940	2.4377	1.3828	0.7735	0.6378	6.9907	EC
60	0	2.447	3.814	4.990	5.771	9.241	11.202	10.418	6.438	4.052	2.985	2.149	1.940	5.461	MEAN
		0.8053	1.3252	1.8398	1.7208	2.3958	2.8541	2.3236	1.7590	1.2791	1.0156	0.6743	0.6052	3.5513	SD
90	0	2.510	4.166	5.374	5.102	6.242	7.054	6.587	4.948	3.506	2.535	1.908	1.949	4.324	MOYEN
		0.8971	1.3103	1.9151	1.4052	1.4062	1.5137	1.3102	1.0696	0.8184	0.7239	0.6704	0.7399	2.1332	EC
30	270	4.686	8.746	13.250	16.857	19.706	19.800	20.497	17.863	12.471	7.573	4.285	3.779	12.472	MEAN
		2.4368	3.9824	5.5590	7.2744	7.4453	7.5508	6.4086	6.0194	5.2841	3.8451	2.3854	2.1467	8.2302	SD
60	270	4.545	8.530	12.335	14.881	16.929	16.785	17.544	15.592	11.057	6.786	3.972	3.697	11.062	MOYEN
		2.5755	4.1893	5.4752	6.7177	6.5109	6.6114	5.6490	5.4613	4.9011	3.6716	2.4472	2.3029	7.1670	EC
90	270	4.138	7.782	10.774	11.898	12.892	12.664	13.303	12.063	8.712	5.400	3.331	3.364	8.861	MEAN
		2.4644	3.9762	5.0629	5.5907	5.0379	5.0724	4.3432	4.3548	3.9773	3.0417	2.1951	2.2351	5.5816	SD
30	225	6.781	11.936	16.433	19.170	20.948	20.433	21.412	19.629	14.667	9.634	5.831	5.635	14.381	MOYEN
		4.5356	6.4537	7.7061	8.8335	8.3179	7.9700	6.9253	6.9845	6.8212	5.6723	4.1521	4.2737	8.9765	EC
60	225	7.679	13.062	16.587	17.559	17.936	16.970	18.055	17.457	13.855	9.652	6.235	6.505	13.459	MEAN
		5.7567	7.7569	8.3455	8.5467	7.1332	6.6181	5.8367	6.3711	6.8463	6.2543	5.0810	5.5545	8.1366	SD
90	225	7.232	11.983	14.165	13.433	12.642	11.598	12.477	12.739	10.752	7.929	5.526	6.179	10.542	MOYEN
		5.6441	7.3377	7.3581	6.6702	4.8110	4.2492	3.8079	4.6043	5.4065	5.3719	4.7970	5.5175	6.2716	EC
30	180	7.748	13.365	17.853	19.970	20.942	20.180	21.140	19.870	15.453	10.527	6.513	6.501	15.006	MEAN
		5.5174	7.5982	8.7441	9.3203	8.5795	7.9169	7.0394	7.3152	7.3915	6.4796	4.9254	5.2714	9.2137	SD
60	180	9.353	15.454	18.643	18.166	17.146	15.882	16.849	17.133	14.742	11.077	7.409	8.004	14.141	MOYEN
		7.4498	9.6533	9.8268	8.8325	6.8959	5.9269	5.4343	6.4105	7.4702	7.5135	6.4047	7.2770	8.4894	EC
90	180	9.124	14.518	15.879	12.873	10.521	9.322	9.933	11.172	11.021	9.338	6.831	7.886	10.677	MEAN
		7.5488	9.3331	8.6167	6.2185	3.6295	2.7486	2.6337	3.9205	5.5941	6.5930	6.2662	7.4749	6.7290	SD
30	135	6.781	11.893	16.550	19.203	20.647	20.122	20.856	19.143	14.444	9.538	5.776	5.627	14.220	MOYEN
		4.5441	6.4900	8.0348	8.8376	8.7815	8.1830	7.3706	7.2634	6.7745	5.6411	4.0687	4.2800	9.0168	EC
60	135	7.679	12.994	16.798	17.621	17.524	16.599	17.317	16.751	13.509	9.498	6.144	6.492	13.238	MEAN
		5.7675	7.8189	8.8823	8.5397	7.7805	6.9476	6.4723	6.7697	6.7766	6.1944	4.9426	5.5603	8.2443	SD
90	135	7.236	11.911	14.398	13.500	12.295	11.316	11.873	12.109	10.406	7.773	5.431	6.164	10.354	MOYEN
		5.6644	7.4224	7.9628	6.6607	5.3949	4.5770	4.3918	4.9632	5.3563	5.3194	4.6619	5.5251	6.4219	EC
30	90	4.693	8.705	13.415	16.905	19.283	19.335	19.698	17.193	12.183	7.461	4.237	3.774	12.251	MEAN
		2.4732	4.0671	6.0402	7.3144	8.1127	7.8866	7.0725	6.4172	5.2468	3.8133	2.3173	2.1751	8.2637	SD
60	90	4.554	8.481	12.562	14.953	16.380	16.203	16.510	14.702	10.663	6.637	3.896	3.691	10.775	MOYEN
		2.6355	4.3116	6.1626	6.7633	7.3838	7.1174	6.5438	5.9651	4.8794	3.6414	2.3610	2.3443	7.2596	EC
90	90	4.139	7.718	10.947	11.941	12.411	12.094	12.379	11.261	8.363	5.259	3.250	3.353	8.592	MEAN
		2.5286	4.1087	5.6990	5.6016	5.7872	5.5065	5.0893	4.7643	3.9847	3.0361	2.1244	2.2719	5.6911	SD

MONTREAL JEAN BREBEUF (QUE) (7025280)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	5.273	8.608	12.415	16.376	19.109	20.796	20.794	17.798	13.194	8.412	4.361	3.870	12.605	MEAN
		2.5088	3.8773	5.8318	7.6180	8.8130	7.9506	6.2276	6.0905	5.6557	4.3516	2.7403	2.1650	8.4032	SD
30	0	2.394	3.725	7.054	11.350	15.360	17.487	17.162	13.403	8.224	3.871	2.143	1.964	8.712	MOYEN
		1.0149	1.6089	2.5845	4.3713	6.3143	6.0642	4.5613	3.8239	2.8194	1.4802	0.9143	0.8681	6.8138	EC
60	0	2.490	3.719	4.680	5.407	8.767	10.932	10.427	6.946	4.161	2.814	2.004	1.984	5.374	MEAN
		0.8586	1.2979	1.7751	1.9326	2.7205	2.8397	2.0462	1.8109	1.4846	1.0578	0.8118	0.7874	3.5372	SD
90	0	2.622	4.022	4.872	4.691	5.795	6.729	6.616	5.260	3.608	2.459	1.815	2.012	4.211	MOYEN
		0.9078	1.3162	1.8185	1.5591	1.5633	1.4868	1.1153	1.1641	1.0381	0.7807	0.8042	0.8457	2.0747	EC
30	270	5.275	8.615	12.015	15.370	17.481	19.247	19.064	16.625	12.370	7.925	4.216	3.878	11.859	MEAN
		2.6227	4.0030	5.7863	7.2137	8.0418	7.1974	5.8852	5.6431	5.3158	4.1982	2.7221	2.3176	7.7389	SD
60	270	5.142	8.356	11.054	13.242	14.511	15.844	15.712	14.106	10.642	6.956	3.881	3.764	10.277	MOYEN
		2.7955	4.2126	5.6839	6.4900	6.8751	6.0521	5.2118	5.0064	4.7759	3.8958	2.6978	2.4587	6.5626	EC
90	270	4.669	7.552	9.504	10.325	10.839	11.610	11.588	10.673	8.233	5.462	3.245	3.408	8.093	MEAN
		2.6851	4.0316	5.1665	5.2163	5.2013	4.5309	3.9759	3.9197	3.8216	3.1976	2.3890	2.3482	5.0264	SD
30	225	7.745	11.571	14.685	17.497	18.754	20.082	20.138	18.253	14.657	10.333	5.822	5.705	13.782	MOYEN
		4.9213	6.3924	7.8021	8.6735	8.8662	7.6993	6.2814	6.5521	6.8098	6.1645	4.6079	4.3807	8.5216	EC
60	225	8.850	12.590	14.634	15.783	15.634	16.430	16.592	15.877	13.566	10.286	6.221	6.548	12.748	MEAN
		6.2645	7.6506	8.3915	8.1872	7.4876	6.2307	5.3375	5.8626	6.6444	6.6265	5.4810	5.6521	7.6681	SD
90	225	8.332	11.472	12.341	11.842	10.808	11.057	11.300	11.415	10.318	8.348	5.489	6.196	9.895	MOYEN
		6.1275	7.2334	7.3546	6.2435	4.9889	3.9393	3.4867	4.1472	5.1447	5.5772	5.0946	5.5857	5.9347	EC
30	180	8.816	12.793	15.785	18.302	19.200	20.143	20.418	18.764	15.635	11.487	6.565	6.504	14.543	MEAN
		5.9729	7.4712	8.6641	9.2336	9.1167	7.8146	6.3037	6.9263	7.4777	7.0954	5.4956	5.2888	8.8799	SD
60	180	10.701	14.627	16.221	16.536	15.655	15.862	16.341	16.092	14.831	12.144	7.492	7.933	13.692	MOYEN
		8.0772	9.4227	9.5780	8.6285	7.3072	5.8673	4.8446	5.9945	7.4498	8.0978	6.9930	7.2224	8.2106	EC
90	180	10.421	13.621	13.618	11.616	9.578	9.306	9.804	10.563	11.021	10.206	6.899	7.775	10.343	MEAN
		8.1643	9.0813	8.2728	5.9868	3.9373	2.7842	2.3585	3.5749	5.5214	7.0180	6.7600	7.3700	6.5496	SD
30	135	7.613	11.320	14.603	17.591	19.195	20.046	20.365	18.334	14.780	10.497	5.849	5.616	13.832	MOYEN
		4.8854	6.3810	7.8629	8.8406	9.1900	7.9943	6.4218	6.9306	7.0223	6.2793	4.6610	4.2686	8.6964	EC
60	135	8.621	12.168	14.510	15.933	16.338	16.411	16.950	15.992	13.778	10.559	6.263	6.394	12.828	MEAN
		6.2018	7.6132	8.4632	8.4209	7.9453	6.6279	5.5138	6.4423	6.9844	6.8175	5.5638	5.4587	7.8956	SD
90	135	8.074	11.014	12.211	11.973	11.404	11.042	11.600	11.528	10.536	8.637	5.538	6.022	9.955	MOYEN
		6.0656	7.1856	7.4188	6.4667	5.3714	4.2207	3.6748	4.6911	5.4746	5.7856	5.1886	5.3706	6.0879	EC
30	90	5.122	8.330	11.928	15.503	18.099	19.208	19.384	16.733	12.548	8.121	4.250	3.782	11.940	MEAN
		2.6069	4.0209	5.8951	7.4507	8.4808	7.6081	6.0820	6.1371	5.5968	4.3173	2.7937	2.2065	7.9920	SD
60	90	4.939	7.969	10.928	13.419	15.358	15.813	16.160	14.243	10.892	7.216	3.926	3.635	10.389	MOYEN
		2.7743	4.1889	5.8054	6.8091	7.4095	6.5550	5.5122	5.6822	5.1484	4.0407	2.8055	2.3173	6.8908	EC
90	90	4.482	7.178	9.363	10.469	11.472	11.572	11.915	10.808	8.419	5.703	3.286	3.282	8.167	MEAN
		2.6638	3.9751	5.2668	5.5385	5.6173	4.9004	4.2321	4.5140	4.1340	3.3328	2.5057	2.2224	5.2790	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

MONTREAL JEAN BREBEUF (QUE) LATITUDE 45 DEG 30 MIN LONGITUDE 73 DEG 37 MIN PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0 DEG.	5.273	8.608	12.415	16.376	19.109	20.796	20.794	17.798	13.194	8.412	4.361	3.870	12.609	MEAN
	2.513	3.885	5.842	7.631	8.828	7.965	6.239	6.101	5.665	4.359	2.745	2.169	8.399	S.D.
LATITUDE	10.042	14.083	16.403	17.845	17.809	18.372	18.762	17.829	15.630	12.157	7.206	7.427	14.465	MOYEN
	7.299	8.760	9.428	9.225	8.468	7.052	5.754	6.684	7.726	7.880	6.481	6.498	8.690	EC.T.
LAT.+15 DEG	10.715	14.635	16.203	16.478	15.569	15.763	16.245	16.019	14.791	12.133	7.472	7.944	13.656	MEAN
	8.109	9.454	9.591	8.615	7.272	5.830	4.816	5.974	7.446	8.110	7.016	7.252	8.186	S.D.
90 DEG.	10.422	13.622	13.620	11.617	9.579	9.306	9.805	10.563	11.021	10.207	6.878	7.776	10.345	MOYEN
	8.178	9.098	8.288	5.998	3.944	2.789	2.363	3.581	5.531	7.030	6.771	7.382	6.547	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0 DEG.	4.696	7.114	9.366	11.290	12.279	13.169	13.260	11.876	9.546	6.688	3.796	3.525	8.894	MEAN
	2.235	3.154	4.336	5.329	5.821	5.186	4.081	4.180	4.128	3.447	2.386	1.985	5.329	S.D.
LATITUDE	8.753	11.330	12.422	12.851	12.373	12.672	12.962	12.609	11.526	9.541	6.109	6.608	10.810	MOYEN
	6.299	6.973	7.157	6.872	6.282	5.269	4.322	5.054	5.869	6.203	5.455	5.755	6.445	EC.T.
LAT.+15 DEG	9.304	11.711	12.271	12.000	11.071	11.149	11.493	11.518	10.958	9.485	6.302	7.042	10.350	MEAN
	6.971	7.490	7.293	6.510	5.586	4.556	3.780	4.644	5.699	6.364	5.876	6.397	6.291	S.D.
90 DEG.	8.990	10.794	10.298	8.627	7.037	6.728	7.130	7.805	8.242	7.902	5.744	6.849	7.994	MOYEN
	6.978	7.137	6.298	4.644	3.227	2.342	2.014	2.950	4.289	5.465	5.620	6.468	5.259	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0 DEG.	.888	.829	.757	.686	.636	.628	.636	.663	.719	.793	.868	.907	.750	MEAN
	.040	.043	.056	.064	.071	.073	.062	.065	.068	.061	.048	.027	.116	S.D.
LATITUDE	.872	.809	.756	.709	.677	.675	.683	.696	.726	.780	.849	.889	.760	MOYEN
	.059	.058	.064	.068	.075	.074	.063	.069	.077	.077	.070	.046	.101	EC.T.
LAT.+15 DEG	.869	.805	.755	.715	.690	.690	.698	.706	.728	.776	.844	.885	.763	MEAN
	.063	.061	.066	.068	.076	.074	.063	.070	.078	.081	.076	.050	.098	S.D.
90 DEG.	.864	.799	.754	.727	.712	.707	.717	.724	.734	.769	.836	.880	.768	MOYEN
	.069	.065	.066	.066	.078	.076	.065	.069	.078	.086	.084	.055	.093	EC.T.

RIVIERE DU LOUP (QUE) (7056815)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	5.173	8.519	13.270	16.244	19.068	21.491	20.398	17.295	12.616	8.280	4.810	3.928	12.599	MEAN
		2.0920	3.4564	5.2727	6.7036	7.8389	7.4083	6.3553	6.1986	5.3854	3.5251	2.1411	1.6589	8.0648	SD
30	0	2.365	3.637	7.282	11.440	15.368	18.100	16.775	12.743	7.613	3.799	2.431	2.025	8.648	MOYEN
		0.8741	1.4149	2.2638	3.2646	5.2449	5.4925	4.4288	3.6537	2.1597	1.3398	0.8302	0.6800	6.5662	EC
60	0	2.484	3.798	5.364	6.270	9.007	11.298	10.070	6.481	4.052	3.023	2.313	2.061	5.524	MEAN
		0.7253	1.1578	1.8579	1.9019	2.2600	2.3618	1.9493	1.6917	1.4252	1.0634	0.6833	0.5709	3.4301	SD
90	0	2.645	4.147	5.725	5.599	6.376	7.337	6.720	5.053	3.499	2.623	2.151	2.112	4.499	MOYEN
		0.7434	1.1712	1.7391	1.5242	1.4158	1.3374	1.2038	1.0629	0.8467	0.6854	0.6690	0.6017	2.1321	EC
30	270	5.299	8.506	12.920	15.589	18.091	20.083	19.004	16.376	12.072	8.114	4.687	4.051	12.072	MEAN
		2.2069	3.6127	5.1865	6.4021	7.2097	6.7093	5.6627	5.8109	5.2671	3.5749	2.1727	1.8354	7.4915	SD
60	270	5.320	8.377	12.145	13.872	15.677	17.009	16.139	14.200	10.690	7.414	4.427	4.078	10.781	MOYEN
		2.4247	3.8704	5.2546	6.0172	6.3567	5.8853	4.9607	5.2350	4.9630	3.5433	2.2887	2.0711	6.5018	EC
90	270	4.938	7.693	10.727	11.229	12.022	12.838	12.202	10.953	8.432	5.990	3.824	3.795	8.718	MEAN
		2.3638	3.7146	4.9448	5.1256	4.9631	4.5565	3.8411	4.1749	4.0877	3.0397	2.1495	2.0569	5.0812	SD
30	225	7.985	11.651	15.937	17.570	19.160	20.865	20.017	18.061	14.301	10.496	6.620	6.122	14.066	MOYEN
		4.3845	5.9008	7.4484	8.0324	8.1594	7.2332	6.3196	6.9086	7.0044	5.5734	4.1000	3.8629	8.2096	EC
60	225	9.367	12.854	16.233	16.245	16.551	17.374	16.876	16.029	13.558	10.737	7.239	7.241	13.352	MEAN
		5.7210	7.1668	8.3217	7.8854	7.1009	5.9793	5.3193	6.3543	7.1829	6.3591	5.1403	5.1962	7.5132	SD
90	225	9.002	11.889	14.081	12.686	11.885	11.916	11.761	11.765	10.562	8.990	6.560	7.011	10.663	MOYEN
		5.6830	6.8304	7.4820	6.2550	4.8399	3.8339	3.4755	4.5963	5.7558	5.6026	4.9599	5.2541	5.9184	EC
30	180	9.163	13.058	17.260	18.168	19.140	20.772	20.065	18.471	15.176	11.496	7.547	7.051	14.777	MEAN
		5.4257	6.9608	8.5404	8.7160	8.4317	7.4017	6.6200	7.2744	7.6888	6.4630	5.0453	4.8088	8.5292	SD
60	180	11.406	15.211	18.160	16.722	15.854	16.506	16.238	16.060	14.607	12.336	8.838	8.851	14.218	MOYEN
		7.5085	8.9147	9.8689	8.5141	6.9487	5.6273	5.2465	6.4768	7.9676	7.7640	6.7564	6.8220	8.0558	EC
90	180	11.302	14.399	15.729	12.297	10.088	9.798	9.916	10.720	11.062	10.573	8.337	8.846	11.067	MEAN
		7.6885	8.6702	8.8045	6.1910	3.7971	2.5955	2.6183	3.9955	6.0971	6.9867	6.7484	7.0991	6.6174	SD
30	135	7.806	11.592	15.971	17.360	18.887	20.853	20.061	17.986	14.251	10.300	6.681	6.009	13.980	MOYEN
		4.4257	5.9449	7.7581	8.3600	8.5488	7.7963	6.9720	7.1867	7.0591	5.5449	4.2018	3.8406	8.4119	EC
60	135	9.057	12.753	16.284	15.949	16.137	17.380	16.925	15.910	13.487	10.408	7.345	7.046	13.215	MEAN
		5.7742	7.2335	8.7635	8.3735	7.6443	6.7585	6.1986	6.7512	7.2695	6.3041	5.2987	5.1437	7.8049	SD
90	135	8.652	11.787	14.135	12.418	11.529	11.934	11.817	11.655	10.498	8.638	6.681	6.790	10.531	MOYEN
		5.7384	6.9170	7.9378	6.7292	5.3301	4.4682	4.2085	4.9710	5.8526	5.5440	5.1263	5.1924	6.1773	EC
30	90	5.100	8.439	12.961	15.301	17.711	20.072	19.078	16.283	12.008	7.872	4.766	3.935	11.966	MEAN
		2.2916	3.7055	5.6287	6.8139	7.7779	7.5197	6.5906	6.2536	5.3725	3.5635	2.3110	1.8505	7.7627	SD
60	90	5.047	8.286	12.205	13.484	15.167	17.023	16.259	14.087	10.606	7.086	4.531	3.917	10.643	MOYEN
		2.5184	3.9945	5.8345	6.5346	7.0924	6.9142	6.1108	5.8579	5.1075	3.5181	2.4478	2.0818	6.8754	EC
90	90	4.684	7.609	10.778	10.880	11.624	12.827	12.319	10.872	8.365	5.710	3.910	3.635	8.598	MEAN
		2.4428	3.8309	5.4709	5.5748	5.5801	5.3938	4.7727	4.7312	4.2170	3.0102	2.2774	2.0655	5.4150	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

RIVIERE DU LOUP (QUE)   LATITUDE 47 DEG 48 MIN   LONGITUDE 69 DEG 33 MIN   PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	5.173	8.519	13.270	16.244	19.068	21.491	20.398	17.295	12.616	8.280	4.810	3.928	12.604	MEAN
	2.096	3.463	5.281	6.716	7.853	7.422	6.367	6.210	5.395	3.531	2.145	1.662	8.060	S.D.
LATITUDE	10.757	14.678	18.204	17.720	17.603	18.683	18.228	17.474	15.226	12.312	8.520	8.320	14.806	MOYEN
	6.879	8.380	9.627	8.895	7.833	6.589	6.026	7.053	8.136	7.489	6.261	6.201	8.385	EC.T.
LAT.+15 DEG	11.501	15.264	18.072	16.420	15.383	15.932	15.708	15.659	14.393	12.279	8.869	8.931	14.024	MEAN
	7.623	9.005	9.888	8.393	6.713	5.380	5.042	6.314	7.894	7.794	6.844	6.938	7.947	S.D.
90 DEG.	11.303	14.400	15.731	12.299	10.089	9.799	9.916	10.721	11.063	10.573	8.338	8.846	11.072	MOYEN
	7.701	8.686	8.820	6.202	3.804	2.600	2.623	4.002	6.108	6.998	6.761	7.111	6.614	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	4.701	7.105	10.007	11.049	11.914	13.069	12.590	11.338	9.015	6.585	4.235	3.648	8.775	MEAN
	1.895	2.857	3.983	4.700	5.114	4.703	4.207	4.199	3.896	2.769	1.892	1.544	4.913	S.D.
LATITUDE	9.403	11.860	13.744	12.615	12.029	12.704	12.461	12.275	11.081	9.548	7.248	7.372	11.022	MOYEN
	5.999	6.742	7.349	6.722	5.911	4.999	4.660	5.345	6.122	5.830	5.356	5.464	6.254	EC.T.
LAT.+15 DEG	10.003	12.267	13.636	11.817	10.771	11.157	11.036	11.206	10.523	9.469	7.503	7.867	10.595	MEAN
	6.623	7.213	7.551	6.437	5.271	4.312	4.081	4.920	5.980	6.042	5.831	6.088	6.162	S.D.
90 DEG.	9.763	11.475	11.850	9.000	7.275	7.058	7.181	7.898	8.163	8.067	6.993	7.732	8.524	MOYEN
	6.650	6.902	6.728	4.873	3.204	2.318	2.319	3.292	4.681	5.370	5.724	6.199	5.346	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	.909	.834	.753	.676	.620	.605	.612	.652	.712	.798	.881	.928	.748	MEAN
	.033	.041	.043	.054	.050	.046	.049	.046	.053	.045	.049	.024	.123	S.D.
LATITUDE	.877	.810	.751	.698	.666	.667	.671	.690	.718	.776	.854	.893	.756	MOYEN
	.054	.060	.050	.061	.057	.053	.056	.053	.063	.061	.064	.051	.099	EC.T.
LAT.+15 DEG	.872	.806	.750	.704	.680	.685	.688	.701	.720	.772	.849	.888	.760	MEAN
	.059	.064	.051	.061	.060	.057	.058	.054	.065	.065	.067	.055	.095	S.D.
90 DEG.	.867	.800	.748	.714	.701	.706	.710	.720	.725	.764	.842	.883	.765	MOYEN
	.063	.068	.051	.060	.065	.065	.062	.057	.065	.070	.072	.061	.090	EC.T.

FREDERICTON CDA (NB) (8101800)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	5.416	8.604	12.272	15.228	17.219	19.988	19.767	17.652	12.546	8.575	5.017	4.104	12.210	MEAN
		2.5062	3.8255	5.6382	7.2611	8.6472	7.9546	7.5537	6.4269	6.2317	4.4767	2.8988	2.3474	8.1124	SD
30	0	1.908	3.225	6.866	10.839	14.051	17.103	16.345	13.220	7.647	3.465	1.884	1.561	8.177	MOYEN
		0.8925	1.5205	2.4122	4.1444	6.2263	6.1983	5.7388	4.1568	3.0153	1.6254	0.8603	0.7171	6.7773	EC
60	0	2.112	3.290	4.558	5.645	8.314	10.960	9.953	6.737	3.808	2.489	1.808	1.675	5.109	MEAN
		0.7065	1.1606	1.7704	2.1733	2.8708	3.2283	2.8514	2.0451	1.5786	1.1715	0.7412	0.6520	3.6500	SD
90	0	2.392	3.670	4.617	4.750	5.654	6.916	6.375	5.147	3.334	2.254	1.705	1.831	4.050	MOYEN
		0.7882	1.1606	1.6359	1.6333	1.7673	1.8713	1.6938	1.3760	1.1386	0.8666	0.7057	0.7927	2.1817	EC
30	270	5.394	8.423	11.516	14.182	15.981	18.778	18.528	16.516	12.030	8.217	4.766	4.090	11.529	MEAN
		2.5814	3.9583	5.5041	6.9291	7.8901	7.2710	6.9202	6.0189	5.8540	4.3230	2.8752	2.4064	7.5347	SD
60	270	5.341	8.209	10.432	12.228	13.493	15.785	15.640	14.106	10.537	7.393	4.428	4.053	10.129	MOYEN
		2.7735	4.1536	5.3194	6.2673	6.8056	6.2722	5.8825	5.2903	5.2604	4.0367	2.8620	2.5713	6.4442	EC
90	270	4.918	7.452	8.873	9.575	10.199	11.821	11.759	10.805	8.262	5.940	3.727	3.726	8.079	MEAN
		2.6943	3.9613	4.7497	5.0510	5.1977	4.7858	4.4463	4.1298	4.2083	3.3308	2.5156	2.4953	4.9571	SD
30	225	8.535	11.743	14.225	16.008	16.999	19.398	19.379	18.190	14.274	10.934	7.132	6.650	13.613	MOYEN
		5.0067	6.4147	7.5492	8.3522	8.6894	7.6687	7.4842	6.9804	7.5308	6.3806	4.9888	4.8020	8.2260	EC
60	225	9.988	12.830	13.993	14.361	14.343	16.015	16.196	15.872	13.413	11.132	7.813	7.873	12.807	MEAN
		6.3967	7.6825	8.0685	7.9066	7.4060	6.2966	6.1921	6.2622	7.3903	6.9126	5.9425	6.1829	7.4968	SD
90	225	9.478	11.677	11.649	10.787	10.082	10.929	11.166	11.483	10.330	9.191	6.946	7.517	10.089	MOYEN
		6.2825	7.2557	6.9695	6.0091	5.0257	4.0928	4.0708	4.4745	5.7569	5.8754	5.5034	6.1052	5.8991	EC
30	180	10.027	13.365	15.643	16.782	17.257	19.282	19.313	18.736	15.135	12.183	8.343	7.935	14.490	MEAN
		6.1810	7.5735	8.5356	8.9073	8.9339	7.7274	7.6704	7.3598	8.2815	7.3813	6.0365	5.9922	8.5829	SD
60	180	12.567	15.529	16.059	15.105	14.122	15.177	15.448	16.116	14.471	13.128	9.891	10.098	13.961	MOYEN
		8.4306	9.6172	9.4745	8.3570	7.2067	5.8262	5.9696	6.4414	8.3347	8.4905	7.7373	8.2398	8.2010	EC
90	180	12.382	14.515	13.411	10.664	8.804	8.982	9.282	10.597	10.824	11.160	9.246	10.047	10.809	MEAN
		8.5672	9.2901	8.1373	5.7631	3.9525	2.8493	3.0744	3.9748	6.2858	7.4231	7.4833	8.4384	6.8597	SD
30	135	8.599	11.968	14.805	16.338	17.291	19.312	19.133	18.387	14.182	10.970	7.388	6.814	13.757	MOYEN
		5.0685	6.4527	7.8162	8.5319	9.0917	8.0158	7.8600	7.3177	7.7344	6.5314	5.1322	4.9299	8.4008	EC
60	135	10.098	13.212	14.927	14.886	14.779	15.952	15.933	16.213	13.302	11.203	8.253	8.156	13.065	MEAN
		6.5069	7.7726	8.5167	8.2100	7.9773	6.7949	6.7358	6.7972	7.7317	7.1494	6.1956	6.3999	7.8086	SD
90	135	9.603	12.090	12.609	11.294	10.450	10.883	10.962	11.797	10.232	9.278	7.438	7.839	10.360	MOYEN
		6.4091	7.3712	7.4619	6.3364	5.5007	4.4727	4.4950	4.9611	6.1028	6.1197	5.7954	6.3518	6.2149	EC
30	90	5.473	8.694	12.247	14.626	16.393	18.636	18.162	16.794	11.932	8.283	5.067	4.270	11.710	MEAN
		2.6474	3.9796	5.8036	7.1475	8.4485	7.7521	7.4250	6.4840	6.1172	4.5158	3.0375	2.5596	7.7312	SD
60	90	5.449	8.570	11.421	12.842	14.052	15.612	15.195	14.501	10.406	7.487	4.834	4.298	10.383	MOYEN
		2.8649	4.2068	5.7614	6.6086	7.5524	6.9216	6.5752	5.9607	5.6216	4.3092	3.0986	2.7771	6.7542	EC
90	90	5.008	7.780	9.735	10.052	10.645	11.600	11.276	11.076	8.090	5.988	4.093	3.957	8.268	MEAN
		2.7868	4.0350	5.1993	5.3819	5.8345	5.2894	4.9980	4.6890	4.5236	3.5852	2.7545	2.6893	5.2376	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

FREDERICTON CDA (NB) LATITUDE 45 DEG 55 MIN LONGITUDE 66 DEG 37 MIN PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	5.416	8.604	12.272	15.228	17.219	19.988	19.767	17.652	12.546	8.575	5.017	4.104	12.215	MEAN
	2.511	3.832	5.648	7.274	8.662	7.969	7.567	6.438	6.242	4.484	2.904	2.351	8.108	S.D.
LATITUDE	11.689	14.893	16.259	16.292	15.977	17.519	17.690	17.795	15.186	13.050	9.425	9.337	14.585	MOYEN
	7.623	8.946	9.331	8.915	8.295	6.954	7.002	7.117	8.598	8.247	7.176	7.426	8.512	EC.T.
LAT.+15 DEG	12.604	15.546	16.023	15.005	13.981	15.002	15.279	15.981	14.400	13.110	9.905	10.131	13.904	MEAN
	8.481	9.661	9.482	8.318	7.133	5.751	5.901	6.395	8.316	8.504	7.772	8.291	8.166	S.D.
90 DEG.	12.382	14.515	13.411	10.665	8.804	8.982	9.282	10.596	10.823	11.160	9.246	10.047	10.813	MOYEN
	8.581	9.306	8.151	5.773	3.959	2.854	3.079	3.981	6.296	7.435	7.496	8.452	6.856	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	4.823	7.077	9.274	10.539	11.118	12.674	12.697	11.909	9.146	6.827	4.354	3.721	8.686	MEAN
	2.227	3.121	4.233	5.067	5.738	5.148	5.050	4.422	4.603	3.554	2.533	2.146	5.202	S.D.
LATITUDE	10.033	11.770	12.249	11.720	11.164	12.200	12.400	12.718	11.236	10.102	7.846	8.107	10.956	MOYEN
	6.501	7.031	7.061	6.604	6.194	5.210	5.285	5.345	6.523	6.446	5.970	6.445	6.430	EC.T.
LAT.+15 DEG	10.762	12.200	12.055	10.906	10.001	10.746	11.000	11.623	10.698	10.086	9.185	8.747	10.576	MEAN
	7.200	7.547	7.174	6.251	5.519	4.517	4.641	4.920	6.343	6.618	6.425	7.160	6.367	S.D.
90 DEG.	10.486	11.258	10.051	7.891	6.503	6.625	6.915	7.953	8.115	8.477	7.541	8.599	8.359	MOYEN
	7.229	7.189	6.145	4.455	3.268	2.417	2.625	3.213	4.847	5.721	6.126	7.239	5.514	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	.890	.822	.757	.690	.640	.632	.635	.672	.724	.794	.862	.902	.751	MEAN
	.029	.040	.047	.059	.064	.069	.069	.057	.054	.059	.052	.027	.111	S.D.
LATITUDE	.861	.792	.753	.709	.680	.683	.684	.705	.729	.770	.832	.868	.755	MOYEN
	.046	.051	.054	.063	.068	.070	.075	.059	.059	.075	.065	.056	.091	EC.T.
LAT.+15 DEG	.856	.787	.751	.715	.693	.700	.700	.715	.730	.765	.826	.864	.758	MEAN
	.050	.054	.055	.063	.071	.072	.077	.060	.060	.079	.069	.062	.088	S.D.
90 DEG.	.850	.778	.748	.725	.713	.721	.724	.737	.736	.756	.816	.856	.763	MOYEN
	.055	.058	.056	.063	.076	.077	.085	.061	.060	.084	.075	.069	.084	EC.T.

TRURO (NS) (8205990)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	5.505	8.413	12.069	14.508	17.234	20.234	18.792	16.581	12.733	8.605	5.070	4.091	11.995	MEAN
		2.6488	3.9797	5.6370	7.1164	7.9734	7.8875	7.0969	6.4232	5.4098	3.9762	2.5884	2.2208	7.7922	SD
30	0	2.555	3.973	7.272	10.764	14.265	17.261	15.745	12.571	8.074	4.114	2.348	2.107	8.437	MOYEN
		1.1192	1.6319	2.3985	3.9966	5.6327	6.0983	5.3703	4.0125	2.5201	1.3928	0.7834	0.8551	6.3909	EC
60	0	2.617	3.878	5.039	6.106	8.893	11.172	9.905	6.641	4.316	3.040	2.167	2.069	5.493	MEAN
		1.0015	1.4445	1.8378	1.8650	2.3775	2.9992	2.6342	1.7697	1.4900	1.0226	0.6577	0.8120	3.4817	SD
90	0	2.703	4.009	4.898	5.022	6.084	7.028	6.406	5.033	3.682	2.632	1.920	2.016	4.287	MOYEN
		1.0775	1.5770	1.7986	1.3847	1.3963	1.6433	1.4838	1.1448	0.9759	0.7110	0.6119	0.9097	2.0975	EC
30	270	5.427	8.169	11.555	13.726	16.217	19.308	18.105	15.968	12.293	8.428	4.852	4.006	11.513	MEAN
		2.6585	3.9217	5.3547	6.6735	7.2789	7.1923	6.5160	6.0106	5.2852	3.9812	2.5169	2.2352	7.3414	SD
60	270	5.299	7.844	10.533	11.974	13.825	16.362	15.468	13.790	10.779	7.612	4.454	3.870	10.156	MOYEN
		2.8230	4.0617	5.1397	6.0516	6.3070	6.1487	5.6461	5.3046	4.8793	3.8005	2.5149	2.3738	6.3355	EC
90	270	4.811	7.053	8.903	9.417	10.508	12.255	11.621	10.545	8.421	6.073	3.684	3.462	8.063	MEAN
		2.7353	3.8971	4.6018	4.9279	4.8557	4.6422	4.2813	4.1367	3.9494	3.1563	2.2179	2.3003	4.8827	SD
30	225	7.955	10.865	13.874	15.179	17.023	19.784	18.691	17.309	14.312	10.711	6.825	5.888	13.205	MOYEN
		4.9857	6.2411	7.4077	8.0980	8.0754	7.6246	6.9867	6.9848	6.8222	5.8527	4.4630	4.3131	8.0137	EC
60	225	9.001	11.577	13.610	13.638	14.435	16.457	15.784	15.248	13.430	10.805	7.282	6.648	12.323	MEAN
		6.2881	7.3560	7.8614	7.6487	6.8657	6.2100	5.8284	6.2741	6.8890	6.4435	5.3234	5.4922	7.2998	SD
90	225	8.422	10.440	11.353	10.335	10.237	11.262	10.946	11.067	10.343	8.902	6.377	6.201	9.648	MOYEN
		6.1482	6.9353	6.7704	5.8199	4.5956	3.9370	3.7937	4.4449	5.4467	5.5203	4.9215	5.3999	5.6655	EC
30	180	9.158	12.217	14.955	15.690	17.055	19.376	18.285	17.430	14.966	11.636	7.791	6.846	13.783	MEAN
		6.1422	7.4344	8.4577	8.6914	8.3071	7.6934	7.0814	7.3338	7.3955	6.6642	5.4561	5.3722	8.2978	SD
60	180	11.082	13.822	15.147	14.002	13.951	15.241	14.631	14.938	14.176	12.255	8.939	8.307	13.030	MOYEN
		8.2788	9.3168	9.3490	8.1096	6.6229	5.7355	5.4400	6.3937	7.5038	7.7006	7.0032	7.3177	7.8325	EC
90	180	10.761	12.797	12.594	9.925	8.822	9.063	8.891	9.835	10.575	10.295	8.207	8.082	9.968	MEAN
		8.3784	8.9957	8.0204	5.5401	3.4605	2.6930	2.7084	3.8726	5.6454	6.7306	6.7605	7.4661	6.3911	SD
30	135	8.006	11.116	14.058	15.219	16.905	19.084	17.829	16.737	13.962	10.442	6.850	6.026	13.028	MOYEN
		5.1283	6.5508	7.8417	8.4250	8.4698	8.0098	7.3427	7.2268	6.8193	5.7963	4.6902	4.4786	8.0873	EC
60	135	9.090	11.995	13.896	13.718	14.322	15.560	14.619	14.444	12.905	10.356	7.496	6.888	12.100	MEAN
		6.5161	7.8468	8.5206	8.1324	7.4313	6.7667	6.3438	6.6464	6.8560	6.3465	5.6987	5.7647	7.5134	SD
90	135	8.525	10.894	11.637	10.417	10.132	10.553	9.987	10.357	9.837	8.424	6.615	6.472	9.475	MOYEN
		6.4034	7.4795	7.4467	6.2933	5.0932	4.4523	4.3106	4.8160	5.4335	5.4362	5.3373	5.7073	5.9742	EC
30	90	5.491	8.465	11.772	13.783	16.050	18.285	16.860	15.183	11.855	8.087	4.999	4.161	11.255	MEAN
		2.8605	4.3556	5.9332	7.1507	7.8806	7.7731	7.0668	6.3665	5.3419	3.9296	2.8018	2.4460	7.3799	SD
60	90	5.383	8.252	10.819	12.057	13.615	15.032	13.821	12.748	10.210	7.154	4.655	4.079	9.819	MOYEN
		3.0799	4.6589	5.9069	6.6821	7.1090	6.9652	6.4595	5.8121	5.0033	3.7679	2.8946	2.6458	6.4723	EC
90	90	4.883	7.423	9.177	9.457	10.252	11.059	10.182	9.604	7.873	5.685	3.866	3.657	7.756	MEAN
		2.9675	4.4561	5.3114	5.4588	5.5179	5.3537	5.0414	4.6002	4.0950	3.1761	2.5697	2.5555	5.0732	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

TRURO (NS/NE) LATITUDE 45 DEG 22 MIN LONGITUDE 63 DEG 16 MIN PERIOD/PERIODE 1967-1976

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE														
O DEG.	5.505	8.413	12.069	14.508	17.234	20.234	18.792	16.581	12.733	8.605	5.070	4.091	12.000	MEAN
	2.653	3.987	5.646	7.129	7.987	7.902	7.110	6.434	5.419	3.983	2.593	2.225	7.788	S.D.
LATITUDE	10.405	13.357	15.412	15.178	15.825	17.669	16.805	16.562	14.945	12.281	8.607	7.790	13.735	MOYEN
	7.477	8.668	9.206	8.687	7.716	6.931	6.461	7.101	7.719	7.451	6.466	6.580	8.201	EC.T.
LAT.+15 DEG	11.092	13.825	15.133	13.966	13.896	15.171	14.568	14.888	14.147	12.246	8.942	8.314	13.009	MEAN
	8.306	9.343	9.361	8.102	6.600	5.710	5.419	6.381	7.505	7.713	7.023	7.343	7.814	S.D.
90 DEG.	10.761	12.798	12.595	9.926	8.822	9.062	8.891	9.835	10.575	10.295	8.207	8.082	9.973	MOYEN
	8.392	9.011	8.034	5.550	3.466	2.697	2.713	3.879	5.655	6.741	6.772	7.478	6.388	EC.T.
9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE														
O DEG.	4.900	6.901	9.033	9.864	11.034	12.735	12.027	11.150	9.249	6.788	4.404	3.729	8.490	MEAN
	2.372	3.286	4.264	4.899	5.203	5.063	4.589	4.465	3.938	3.128	2.242	2.024	4.927	S.D.
LATITUDE	8.909	10.563	11.510	10.696	10.887	12.164	11.685	11.783	11.029	9.465	7.193	6.759	10.217	MOYEN
	6.413	6.890	7.026	6.379	5.714	5.149	4.792	5.373	5.813	5.797	5.383	5.702	6.134	EC.T.
LAT.+15 DEG	9.441	10.857	11.285	9.939	9.765	10.721	10.374	10.766	10.483	9.384	7.418	7.161	9.793	MEAN
	7.089	7.381	7.144	6.039	5.083	4.451	4.195	4.943	5.684	5.975	5.813	6.331	6.043	S.D.
90 DEG.	9.075	9.932	9.350	7.181	6.371	6.543	6.491	7.306	7.901	7.791	6.717	6.886	7.618	MOYEN
	7.105	7.040	6.112	4.245	2.885	2.278	2.264	3.159	4.321	5.157	5.542	6.396	5.121	EC.T.
RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE														
O DEG.	.891	.820	.746	.679	.638	.627	.639	.669	.727	.790	.869	.913	.750	MEAN
	.048	.044	.050	.054	.057	.056	.058	.057	.050	.048	.047	.023	.112	S.D.
LATITUDE	.860	.793	.741	.695	.673	.676	.685	.700	.734	.771	.840	.878	.754	MOYEN
	.064	.062	.058	.057	.059	.058	.058	.060	.057	.065	.070	.056	.093	EC.T.
LAT.+15 DEG	.854	.787	.739	.700	.685	.692	.699	.710	.736	.767	.834	.872	.756	MEAN
	.068	.066	.060	.057	.061	.061	.058	.060	.058	.069	.075	.062	.090	S.D.
90 DEG.	.847	.779	.736	.709	.703	.708	.717	.728	.741	.758	.825	.863	.759	MOYEN
	.074	.071	.060	.056	.065	.065	.060	.059	.057	.075	.083	.071	.086	EC.T.

CHARLOTTETOWN CDA (PEI) (8300400)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	5.365	8.845	12.580	15.535	18.082	21.591	20.634	17.403	12.782	8.189	4.791	3.708	12.467	MEAN
		2.3640	3.6710	5.4054	7.4255	8.3646	8.1775	7.2927	6.6401	5.6989	4.0689	2.6160	1.9474	8.3357	SD
30	0	2.621	4.197	7.611	11.308	14.817	18.327	17.182	13.198	8.083	3.995	2.415	2.106	8.843	MOYEN
		1.0858	1.9154	2.6863	4.2801	5.9871	6.2801	5.4123	4.2578	2.6953	1.5582	0.9604	0.8448	6.8269	EC
60	0	2.673	4.165	5.548	6.373	9.042	11.716	10.665	7.057	4.386	3.038	2.212	2.045	5.753	MEAN
		0.9306	1.6291	2.2665	2.3474	2.9273	3.1018	2.6220	2.1894	1.6974	1.1341	0.8482	0.7874	3.7651	SD
90	0	2.745	4.348	5.500	5.437	6.268	7.433	6.933	5.386	3.734	2.591	1.936	1.964	4.526	MOYEN
		0.9500	1.5483	2.0816	1.8203	1.9184	1.8273	1.6038	1.4848	1.1511	0.8499	0.7740	0.8417	2.3598	EC
30	270	5.303	8.654	12.226	14.822	16.970	20.448	19.624	16.483	12.274	7.852	4.687	3.685	11.930	MEAN
		2.4540	3.7275	5.3423	7.1218	7.7742	7.6868	6.7602	6.2638	5.4670	4.0309	2.5966	2.0552	7.8653	SD
60	270	5.173	8.368	11.359	13.072	14.448	17.340	16.760	14.204	10.822	7.003	4.346	3.567	10.545	MOYEN
		2.6463	3.9237	5.3214	6.5531	6.7976	6.6956	5.9023	5.6205	5.0399	3.7942	2.5766	2.2161	6.8231	EC
90	270	4.715	7.580	9.814	10.422	10.926	13.008	12.653	10.871	8.473	5.553	3.614	3.202	8.404	MEAN
		2.5752	3.7797	4.8964	5.4284	5.2424	5.0760	4.5064	4.4301	4.0819	3.1234	2.2624	2.1548	5.2839	SD
30	225	7.745	11.547	14.645	16.472	17.919	21.057	20.399	17.968	14.352	10.059	6.444	5.269	13.661	MOYEN
		4.6510	5.9785	7.2841	8.5697	8.5722	8.1104	7.2927	7.2354	7.0932	5.8433	4.4090	3.9104	8.5255	EC
60	225	8.781	12.401	14.562	15.020	15.256	17.539	17.212	15.788	13.477	10.034	6.891	5.940	12.738	MEAN
		5.9591	7.1738	7.8993	8.1972	7.3843	6.7370	6.1298	6.5439	7.1150	6.3511	5.2258	5.0600	7.7107	SD
90	225	8.256	11.281	12.398	11.558	10.828	12.031	11.996	11.499	10.438	8.212	6.073	5.569	10.002	MOYEN
		5.8749	6.8134	6.9684	6.3626	5.0352	4.3466	4.0465	4.7056	5.6347	5.4030	4.8292	5.0288	5.9474	EC
30	180	8.905	12.977	15.705	16.972	18.006	20.743	20.141	18.310	15.146	11.104	7.252	6.022	14.274	MEAN
		5.7231	7.0810	8.2426	9.1215	8.7461	8.0658	7.4111	7.5966	7.7882	6.6730	5.3011	4.7925	8.7646	SD
60	180	10.788	14.784	16.075	15.345	14.815	16.375	16.164	15.742	14.400	11.703	8.278	7.245	13.464	MOYEN
		7.8114	9.0025	9.2758	8.6140	7.0745	6.0843	5.7740	6.6404	7.9145	7.6749	6.7522	6.5807	8.1081	EC
90	180	10.517	13.794	13.612	11.073	9.405	9.727	9.827	10.438	10.798	9.861	7.605	7.054	10.288	MEAN
		7.9521	8.7272	8.1075	6.0584	3.8745	2.9195	2.9405	4.0641	5.9831	6.7114	6.5063	6.7511	6.4599	SD
30	135	7.792	11.773	14.675	16.319	17.843	20.552	19.801	17.843	14.253	10.139	6.429	5.284	13.562	MOYEN
		4.7150	6.1058	7.5185	8.7504	8.8082	8.2458	7.5866	7.5347	7.2367	5.8511	4.5120	3.9197	8.5612	EC
60	135	8.863	12.783	14.619	14.796	15.143	16.857	16.410	15.615	13.312	10.170	6.865	5.968	12.611	MEAN
		6.0640	7.3643	8.2770	8.4525	7.6914	6.9240	6.5179	6.9818	7.2942	6.3956	5.3982	5.0636	7.8210	SD
90	135	8.351	11.695	12.446	11.361	10.721	11.478	11.334	11.345	10.264	8.357	6.045	5.602	9.904	MOYEN
		5.9940	7.0181	7.3546	6.5804	5.2990	4.5311	4.3526	5.1024	5.7886	5.4789	5.0159	5.0309	6.1048	EC
30	90	5.368	8.927	12.257	14.615	16.871	19.714	18.768	16.310	12.140	7.939	4.669	3.713	11.784	MEAN
		2.5434	3.9337	5.5819	7.3455	8.1409	7.9001	7.1618	6.6492	5.6713	4.0062	2.7102	2.0991	7.8580	SD
60	90	5.259	8.733	11.384	12.804	14.317	16.367	15.640	13.969	10.626	7.121	4.325	3.600	10.350	MOYEN
		2.7658	4.1969	5.6329	6.7962	7.2768	7.0228	6.3757	6.0998	5.2883	3.7951	2.7212	2.2680	6.8415	EC
90	90	4.782	7.909	9.850	10.172	10.819	12.177	11.675	10.663	8.329	5.674	3.597	3.224	8.239	MEAN
		2.6870	4.0330	5.1961	5.5996	5.6465	5.3918	4.8682	4.8264	4.3085	3.1541	2.3911	2.1984	5.3345	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

CHARLOTTETOWN CDA (PEI/IPE)   LATITUDE 46 DEG 15 MIN   LONGITUDE 63 DEG 8 MIN   PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	5.365	8.845	12.580	15.535	18.082	21.591	20.634	17.403	12.782	8.189	4.791	3.708	12.472	MEAN
	2.368	3.678	5.414	7.439	8.379	8.192	7.306	6.652	5.709	4.076	2.621	1.951	8.331	S.D.
LATITUDE	10.175	14.291	16.270	16.473	16.661	18.822	18.422	17.345	15.129	11.738	8.013	6.849	14.181	MOYEN
	7.082	8.387	9.087	9.148	8.117	7.245	6.757	7.334	8.136	7.465	6.293	5.950	8.561	EC.T.
LAT.+15 DEG	10.822	14.800	16.028	15.214	14.619	16.121	15.928	15.565	14.303	11.674	8.285	7.267	13.378	MEAN
	7.871	9.053	9.287	8.559	6.972	5.973	5.679	6.571	7.887	7.687	6.789	6.633	8.049	S.D.
90 DEG.	10.517	13.795	13.613	11.075	9.406	9.727	9.827	10.438	10.798	9.861	7.605	7.054	10.293	MOYEN
	7.965	8.743	8.122	6.070	3.881	2.925	2.946	4.071	5.993	6.723	6.518	6.763	6.457	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

O DEG.	4.811	7.316	9.460	10.645	11.696	13.510	13.084	11.633	9.219	6.524	4.184	3.395	8.794	MEAN
	2.108	2.998	4.059	5.163	5.525	5.284	4.819	4.494	4.129	3.249	2.283	1.792	5.241	S.D.
LATITUDE	8.803	11.376	12.174	11.734	11.605	12.951	12.741	12.291	11.064	9.119	6.722	6.029	10.547	MOYEN
	6.073	6.637	6.858	6.805	6.042	5.431	5.081	5.457	6.083	5.864	5.277	5.205	6.327	EC.T.
LAT.+15 DEG	9.313	11.699	11.974	10.946	10.403	11.402	11.305	11.221	10.502	9.017	6.900	6.359	10.079	MEAN
	6.720	7.124	7.006	6.463	5.380	4.698	4.453	5.018	5.932	6.011	5.662	5.774	6.156	S.D.
90 DEG.	8.978	10.783	10.136	8.101	6.884	7.067	7.204	7.744	8.003	7.528	6.256	6.119	7.887	MOYEN
	6.751	6.803	6.105	4.698	3.193	2.492	2.496	3.273	4.555	5.200	5.381	5.842	5.130	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

O DEG.	.897	.828	.752	.683	.644	.621	.629	.667	.720	.796	.872	.913	.752	MEAN
	.025	.036	.047	.052	.058	.057	.063	.058	.055	.053	.041	.026	.114	S.D.
LATITUDE	.871	.800	.746	.701	.681	.673	.678	.699	.725	.775	.841	.886	.756	MOYEN
	.048	.051	.054	.057	.061	.063	.065	.060	.060	.069	.066	.055	.095	EC.T.
LAT.+15 DEG	.867	.795	.745	.705	.693	.690	.694	.709	.727	.770	.836	.882	.759	MEAN
	.052	.054	.056	.058	.063	.067	.067	.060	.061	.074	.072	.061	.092	S.D.
90 DEG.	.861	.787	.742	.715	.712	.710	.718	.728	.732	.762	.826	.875	.764	MOYEN
	.058	.058	.056	.057	.069	.075	.071	.061	.060	.079	.081	.070	.088	EC.T.

ST.JOHN'S A (NFLD) (8403506)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	4.246	6.877	9.697	12.167	14.899	17.569	18.728	14.148	11.366	6.734	3.822	2.970	10.279	MEAN
		2.1938	3.6532	5.1461	6.8779	8.1621	8.9074	7.9283	7.3240	5.5555	3.5097	2.1247	1.5956	7.7967	SD
30	0	2.241	3.458	6.167	9.173	12.370	15.085	15.471	10.828	7.209	3.499	2.040	1.701	7.453	MOYEN
		0.8626	1.2935	2.3374	3.8899	5.8832	7.0407	5.8899	4.6880	2.7075	1.3209	0.7807	0.6258	6.1882	EC
60	0	2.223	3.397	4.711	5.706	7.931	10.058	9.503	6.127	4.179	2.828	1.827	1.612	5.015	MEAN
		0.8518	1.2428	1.7720	1.7467	2.7970	3.8665	2.9062	2.0539	1.5873	0.9948	0.6783	0.6146	3.4397	SD
90	0	2.197	3.417	4.444	4.850	5.755	6.760	6.383	4.731	3.508	2.344	1.536	1.490	3.953	MOYEN
		0.9572	1.4449	1.8413	1.5648	1.8875	2.4143	1.8512	1.5036	1.1561	0.7668	0.5803	0.6762	2.3002	EC
30	270	4.248	6.828	9.509	11.792	14.298	16.833	18.188	13.773	11.098	6.521	3.719	3.020	9.995	MEAN
		2.2615	3.6893	5.0747	6.7343	7.7072	8.3965	7.6019	6.9379	5.5775	3.5568	2.1400	1.7687	7.4977	SD
60	270	4.152	6.593	8.792	10.480	12.357	14.394	15.661	12.022	9.871	5.873	3.411	2.935	8.885	MOYEN
		2.4141	3.8142	4.9740	6.2233	6.8116	7.3294	6.7343	6.1524	5.2361	3.4329	2.1173	1.9348	6.5851	EC
90	270	3.758	5.909	7.484	8.387	9.440	10.819	11.816	9.232	7.762	4.676	2.791	2.598	7.058	MEAN
		2.3341	3.6237	4.4741	5.1136	5.2789	5.5702	5.1765	4.8291	4.2700	2.8619	1.8343	1.8662	5.1114	SD
30	225	6.118	8.950	11.172	12.927	14.957	17.264	18.886	14.862	12.880	8.222	5.099	4.340	11.311	MOYEN
		4.0732	5.7217	6.7999	8.0226	8.4474	8.8226	8.1317	8.0172	7.0603	5.1668	3.6379	3.2743	8.1436	EC
60	225	6.940	9.602	11.058	11.859	12.933	14.556	16.139	13.252	12.224	8.231	5.428	4.948	10.596	MEAN
		5.1558	6.7355	7.3077	7.7211	7.3782	7.4190	6.9812	7.2877	7.1810	5.7278	4.3581	4.2706	7.4215	SD
90	225	6.534	8.720	9.371	9.254	9.385	10.190	11.337	9.779	9.552	6.800	4.759	4.645	8.354	MOYEN
		5.0891	6.3638	6.4097	6.0061	5.1380	4.9215	4.6911	5.2918	5.7596	4.9758	4.0532	4.2701	5.6835	EC
30	180	6.986	9.899	11.832	13.182	14.849	16.960	18.463	14.884	13.417	8.974	5.730	4.926	11.677	MEAN
		4.9527	6.6916	7.6244	8.4133	8.5704	8.7920	8.0945	8.3509	7.5535	5.8278	4.3393	3.9375	8.2906	SD
60	180	8.444	11.185	11.988	11.963	12.395	13.646	15.010	12.902	12.814	9.438	6.516	5.962	11.014	MOYEN
		6.6653	8.3276	8.4733	7.9514	7.0689	6.8414	6.4476	7.4065	7.7216	6.7645	5.5545	5.4050	7.6135	EC
90	180	8.228	10.389	10.123	8.839	8.201	8.516	9.314	8.748	9.718	8.002	5.967	5.800	8.472	MEAN
		6.7783	8.0314	7.4021	5.6263	4.1019	3.6482	3.4699	4.7331	5.9442	5.9878	5.3719	5.5491	5.8669	SD
30	135	6.089	8.896	11.024	12.616	14.511	16.678	17.814	14.225	12.470	8.162	5.081	4.249	10.988	MOYEN
		4.1262	5.8304	7.0137	7.9824	8.5591	8.9406	8.1050	8.1234	6.8759	5.0424	3.6559	3.1766	8.0142	EC
60	135	6.891	9.507	10.810	11.377	12.284	13.724	14.659	12.311	11.582	8.129	5.398	4.789	10.118	MEAN
		5.2240	6.8909	7.6281	7.6732	7.5104	7.5830	6.9555	7.4456	6.8998	5.5075	4.3762	4.0867	7.2852	SD
90	135	6.478	8.618	9.118	8.806	8.829	9.485	10.090	8.938	8.922	6.687	4.728	4.465	7.922	MOYEN
		5.1576	6.5304	6.7525	5.9975	5.2658	5.1083	4.7053	5.4321	5.5000	4.7445	4.0668	4.0524	5.6263	EC
30	90	4.220	6.760	9.301	11.362	13.663	15.980	16.643	12.893	10.560	6.443	3.704	2.922	9.545	MEAN
		2.3643	3.8598	5.3280	6.6608	7.8696	8.6077	7.5755	7.0949	5.3472	3.4485	2.1868	1.6935	7.2788	SD
60	90	4.114	6.513	8.512	9.897	11.503	13.223	13.593	10.853	9.153	5.770	3.389	2.799	8.279	MOYEN
		2.5336	4.0560	5.2992	6.1509	6.9952	7.6313	6.6819	6.3320	4.9503	3.3015	2.1722	1.8208	6.3215	EC
90	90	3.717	5.835	7.273	7.909	8.731	9.863	10.047	8.224	7.150	4.591	2.766	2.468	6.547	MEAN
		2.4333	3.8499	4.7819	5.0954	5.4390	5.8580	5.0897	4.9376	4.0517	2.7603	1.8683	1.7481	4.9302	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

ST. JOHN'S A (NFLD/TN) LATITUDE 47 DEG 31 MIN LONGITUDE 52 DEG 47 MIN PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	4.379	7.034	10.398	13.340	16.433	19.081	19.897	14.933	11.940	6.923	3.930	3.067	10.964	MEAN
	2.099	3.553	4.799	6.853	7.881	7.920	7.307	7.130	5.393	3.575	2.126	1.635	7.917	S.D.
LATITUDE	8.064	10.940	12.760	13.774	15.095	16.697	17.870	14.751	13.846	9.632	6.366	5.695	12.124	MOYEN
	5.959	7.667	7.884	8.283	7.682	7.041	6.851	7.828	7.689	6.596	5.098	4.954	7.998	EC.T.
LAT.+15 DEG	8.502	11.217	12.430	12.710	13.347	14.466	15.523	13.254	13.046	9.520	6.519	6.004	11.375	MEAN
	6.566	8.179	8.006	7.710	6.646	5.860	5.785	7.039	7.450	6.775	5.474	5.481	7.405	S.D.
90 DEG.	8.208	10.378	10.539	9.588	9.163	9.438	10.025	9.238	10.024	8.095	5.941	5.783	8.861	MOYEN
	6.615	7.851	7.025	5.561	3.997	3.161	3.184	4.601	5.794	5.987	5.252	5.552	5.745	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	3.926	5.836	7.906	9.320	10.743	12.036	12.732	10.106	8.711	5.534	3.442	2.813	7.766	MEAN
	1.868	2.911	3.640	4.856	5.250	5.104	4.842	4.935	3.950	2.878	1.865	1.517	5.063	S.D.
LATITUDE	6.977	8.795	9.660	9.922	10.472	11.359	12.368	10.502	10.248	7.527	5.408	5.020	9.020	MOYEN
	5.122	6.127	6.032	6.221	5.703	5.214	5.160	5.860	5.821	5.220	4.351	4.375	5.892	EC.T.
LAT.+15 DEG	7.316	8.964	9.395	9.225	9.406	10.043	10.976	9.572	9.693	7.399	5.506	5.261	8.559	MEAN
	5.621	6.507	6.120	5.869	5.090	4.524	4.522	5.384	5.672	5.337	4.653	4.817	5.635	S.D.
90 DEG.	7.007	8.216	7.937	7.031	6.562	6.658	7.248	6.818	7.508	6.228	4.968	5.023	6.761	MOYEN
	5.624	6.196	5.343	4.326	3.202	2.581	2.637	3.664	4.454	4.669	4.430	4.843	4.552	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	.896	.830	.760	.694	.649	.628	.635	.671	.729	.798	.875	.914	.756	MEAN
	.028	.040	.052	.063	.063	.057	.054	.071	.058	.057	.039	.024	.113	S.D.
LATITUDE	.870	.806	.754	.707	.678	.667	.679	.696	.734	.780	.852	.884	.759	MOYEN
	.045	.054	.061	.066	.063	.060	.059	.073	.063	.072	.059	.051	.097	EC.T.
LAT.+15 DEG	.865	.802	.752	.710	.686	.678	.692	.704	.736	.776	.848	.879	.761	MEAN
	.049	.058	.063	.066	.064	.062	.061	.074	.064	.076	.065	.057	.094	S.D.
90 DEG.	.859	.795	.749	.716	.696	.690	.708	.717	.741	.769	.840	.872	.763	MOYEN
	.054	.062	.064	.065	.066	.067	.066	.075	.062	.082	.073	.065	.091	EC.T.

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

WHITEHORSE A (YT/TY) LATITUDE 60 DEG 43 MIN LONGITUDE 135 DEG 4 MIN PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	1.305	4.042	9.351	14.998	19.277	20.765	18.382	14.581	8.809	4.416	1.711	.724	9.922	MEAN
	.669	1.780	3.038	4.254	5.098	5.681	5.358	4.854	3.471	2.050	.899	.317	8.045	S.D.
LATITUDE	6.036	11.289	16.614	18.090	18.345	17.829	16.480	15.525	12.312	9.290	5.862	3.953	12.651	MOYEN
	4.091	6.654	7.103	6.476	5.962	5.604	5.570	6.299	6.574	5.922	4.256	2.802	7.651	EC.T.
LAT.+15 DEG	6.415	11.616	16.265	16.535	15.912	15.112	14.123	13.802	11.574	9.285	6.132	4.236	11.766	MEAN
	4.392	6.959	7.126	6.032	5.193	4.671	4.719	5.660	6.356	6.051	4.518	3.040	6.893	S.D.
90 DEG.	6.403	11.285	15.097	14.291	13.085	12.211	11.514	11.589	10.313	8.785	6.045	4.257	10.420	MOYEN
	4.408	6.820	6.710	5.239	4.172	3.589	3.704	4.720	5.754	5.800	4.489	3.078	5.975	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	1.287	3.594	7.101	9.633	11.065	11.352	10.491	9.029	6.269	3.706	1.644	.722	6.355	MEAN
	.654	1.491	2.155	2.743	3.202	3.443	3.277	3.110	2.499	1.666	.839	.316	4.514	S.D.
LATITUDE	6.006	9.763	12.641	12.599	12.189	11.635	10.955	10.671	8.982	7.628	5.621	3.952	9.396	MOYEN
	4.067	5.707	5.456	4.913	4.584	4.306	4.240	4.740	5.039	4.912	4.021	2.801	5.425	EC.T.
LAT.+15 DEG	6.384	10.021	12.372	11.665	10.841	10.164	9.641	9.671	8.480	7.601	5.879	4.235	8.921	MEAN
	4.368	5.973	5.491	4.657	4.130	3.752	3.743	4.368	4.898	5.018	4.271	3.040	5.115	S.D.
90 DEG.	6.373	9.713	11.478	10.215	9.074	8.327	7.977	8.271	7.590	7.171	5.793	4.256	8.027	MOYEN
	4.384	5.855	5.180	4.115	3.424	2.979	3.036	3.739	4.455	4.806	4.246	3.077	4.609	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	.988	.898	.765	.644	.572	.544	.568	.618	.712	.844	.967	.998	.758	MEAN
	.015	.045	.050	.055	.054	.052	.058	.064	.060	.054	.027	.005	.173	S.D.
LATITUDE	.994	.867	.759	.688	.654	.641	.652	.675	.718	.814	.965	.999	.785	MOYEN
	.011	.065	.053	.060	.057	.058	.062	.067	.066	.076	.042	.002	.144	EC.T.
LAT.+15 DEG	.995	.864	.758	.696	.669	.660	.668	.687	.720	.810	.965	.999	.791	MEAN
	.011	.068	.054	.060	.059	.060	.064	.067	.067	.080	.043	.002	.139	S.D.
90 DEG.	.995	.861	.757	.705	.680	.669	.678	.698	.723	.806	.964	.999	.794	MOYEN
	.011	.070	.055	.059	.060	.061	.065	.068	.067	.083	.045	.002	.136	EC.T,

WHITEHORSE A (YT) (2101300)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	1.305	4.042	9.351	14.998	19.277	20.765	18.382	14.581	8.809	4.416	1.711	0.724	9.918	MEAN
		0.6675	1.7767	3.0324	4.2460	5.0880	5.6705	5.3485	4.8458	3.4645	2.0466	0.8970	0.3163	8.0472	SD
30	0	0.540	1.472	3.373	8.891	14.696	17.378	14.763	9.878	4.359	1.832	0.786	0.343	6.518	MOYEN
		0.2657	0.7029	1.5884	2.3800	3.1239	3.8445	3.7521	2.8209	1.8383	0.8030	0.3658	0.1667	6.4312	EC
60	0	0.534	1.469	3.145	5.613	9.290	11.650	9.625	6.073	3.310	1.685	0.747	0.330	4.453	MEAN
		0.2396	0.5759	1.1880	1.5570	1.9801	2.0711	2.2012	1.6930	1.2448	0.6551	0.3211	0.1453	4.0091	SD
90	0	0.525	1.466	3.100	4.883	7.506	9.293	7.668	4.960	2.805	1.485	0.694	0.312	3.724	MOYEN
		0.2233	0.4891	0.8870	1.0844	1.5032	1.7264	1.7714	1.2776	0.8743	0.4974	0.2841	0.1245	3.1489	EC
30	270	1.463	4.318	9.286	14.297	17.790	19.008	17.055	13.912	8.518	4.479	1.875	0.790	9.403	MEAN
		0.7887	1.9948	3.1560	4.3098	5.0319	5.3293	5.1380	4.6471	3.4567	2.1065	1.0567	0.3765	7.4305	SD
60	270	1.586	4.525	9.165	13.340	15.966	16.839	15.115	12.714	7.963	4.392	1.969	0.860	8.707	MOYEN
		0.9149	2.2585	3.4109	4.4896	5.0997	5.1028	4.9541	4.5422	3.4833	2.2227	1.2007	0.4525	6.7449	EC
90	270	1.510	4.181	8.073	11.159	12.896	13.407	12.000	10.335	6.582	3.786	1.825	0.816	7.220	MEAN
		0.9100	2.1739	3.1929	4.0027	4.4114	4.2404	4.1527	3.8907	3.0414	2.0114	1.1618	0.4553	5.4798	SD
30	225	3.305	7.243	12.827	17.130	19.736	20.284	18.458	15.931	10.721	6.649	3.517	2.057	11.495	MOYEN
		2.0561	3.7837	4.8208	5.5403	5.9378	6.0291	5.8439	5.7704	4.9296	3.6608	2.2784	1.3110	7.9910	EC
60	225	4.555	8.948	14.015	16.725	17.795	17.698	16.346	14.989	10.834	7.560	4.566	2.924	11.421	MEAN
		2.9935	5.0196	5.7934	5.9719	5.9235	5.5538	5.4580	5.7804	5.4876	4.5411	3.1698	2.0046	7.2988	SD
90	225	4.725	8.692	12.530	13.616	13.497	12.975	12.131	11.731	9.040	6.917	4.580	3.091	9.469	MOYEN
		3.1656	5.0141	5.4254	5.0856	4.6490	4.0252	4.0658	4.6142	4.8014	4.3270	3.2612	2.1757	5.6781	EC
30	180	4.146	8.604	14.499	18.341	20.636	20.988	19.028	16.617	11.783	7.682	4.257	2.641	12.444	MEAN
		2.6712	4.7121	5.6480	6.0360	6.2522	6.3552	6.1934	6.3056	5.6908	4.4803	2.8856	1.7581	8.3211	SD
60	180	6.010	11.258	16.610	18.144	18.440	17.939	16.575	15.589	12.329	9.278	5.841	3.935	12.673	MOYEN
		4.0641	6.6175	7.0790	6.4754	5.9780	5.6294	5.5920	6.3087	6.5736	5.8969	4.2300	2.7821	7.6868	EC
90	180	6.405	11.288	15.101	14.294	13.086	12.211	11.514	11.589	10.313	8.787	6.047	4.259	10.418	MEAN
		4.4017	6.8089	6.6994	5.2310	4.1652	3.5833	3.6975	4.7117	5.7543	5.7916	4.4828	3.0741	5.9802	SD
30	135	3.264	7.129	13.058	17.774	20.915	21.509	19.167	16.220	11.045	6.667	3.428	2.069	11.862	MOYEN
		2.0564	3.8357	5.0129	5.9046	6.3282	6.5627	6.3817	6.3031	5.2673	3.8561	2.2634	1.3282	8.5050	EC
60	135	4.483	8.755	14.395	17.734	19.502	19.380	17.361	15.436	11.352	7.586	4.415	2.945	11.956	MEAN
		2.9922	5.1203	6.0946	6.5052	6.4340	6.2987	6.2096	6.5804	6.0113	4.8346	3.1610	2.0357	8.0103	SD
90	135	4.643	8.475	12.942	14.617	15.045	14.430	13.040	12.169	9.580	6.937	4.407	3.115	9.960	MOYEN
		3.1639	5.1320	5.7425	5.6171	5.0940	4.6730	4.7317	5.4010	5.3407	4.6292	3.2599	2.2123	6.2990	EC
30	90	1.415	4.198	9.578	15.154	19.460	20.796	18.085	14.306	8.918	4.499	1.782	0.801	9.920	MEAN
		0.7931	2.0057	3.4177	4.7821	5.6218	6.1563	5.8967	5.3525	3.8602	2.3561	1.0071	0.3865	8.1699	SD
60	90	1.521	4.358	9.563	14.472	18.167	19.189	16.487	13.238	8.506	4.421	1.840	0.876	9.393	MOYEN
		0.9199	2.2852	3.7668	5.1218	5.8487	6.2230	5.9427	5.4878	4.0520	2.5622	1.1481	0.4700	7.7228	EC
90	90	1.452	4.017	8.428	12.163	14.804	15.431	13.165	10.800	7.084	3.820	1.699	0.833	7.815	MEAN
		0.9144	2.2136	3.5231	4.6029	5.0564	5.2451	5.0120	4.7312	3.5781	2.3390	1.1210	0.4758	6.3323	SD

GLOBAL SOLAR RADIATION (MJ/M^2) INCIDENT ON A HORIZONTAL SURFACE AND ON THREE SOUTH-FACING TILTED SURFACES

RAYONNEMENT SOLAIRE GLOBAL (MJ/M^2) SUR UNE SURFACE HORIZONTALE ET SUR TROIS SURFACES INCLINEES, ORIENTEES AU SUD

FROBISHER BAY A (NWT/TNO)   LATITUDE 63 DEG 45 MIN   LONGITUDE 68 DEG 33 MIN   PERIOD/PERIODE 1967-1976

DAILY RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	.871	3.881	10.568	18.184	20.130	17.848	16.086	11.907	6.925	3.551	1.127	.341	9.255	MEAN
	.582	1.803	3.380	5.582	7.045	7.661	7.247	5.363	3.182	1.772	.691	.164	8.456	S.D.
LATITUDE	5.312	13.636	22.848	26.395	21.442	15.686	14.685	12.801	9.472	7.688	4.878	2.367	13.004	MOYEN
	3.852	7.243	8.423	10.134	9.372	7.538	7.446	7.279	5.977	5.965	3.996	1.607	10.054	EC.T.
LAT.+15 DEG	5.664	14.223	23.074	25.622	19.782	13.505	12.597	11.375	8.904	7.780	5.149	2.534	12.419	MEAN
	4.112	7.578	8.562	9.896	8.806	6.375	6.331	6.555	5.731	6.181	4.252	1.730	9.609	S.D.
90 DEG.	5.698	14.125	22.472	24.332	18.166	11.669	10.783	9.967	8.200	7.592	5.153	2.557	11.630	MOYEN
	4.135	7.514	8.307	9.334	8.156	5.361	5.305	5.733	5.309	6.090	4.266	1.749	9.050	EC.T.

9 AM TO 3 PM RADIATION: MEAN AND STANDARD DEVIATION/RAYONNEMENT DE 9 H A 15 H: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG	.867	3.536	8.076	11.788	11.649	9.657	9.027	7.313	4.969	3.018	1.106	.341	5.920	MEAN
	.578	1.532	2.353	3.485	4.152	4.367	4.208	3.401	2.231	1.453	.670	.164	4.875	S.D.
LATITUDE	5.309	12.226	17.498	18.662	14.169	10.034	9.741	8.801	7.023	6.446	4.825	2.367	9.684	MOYEN
	3.849	6.258	6.457	7.399	6.815	5.589	5.496	5.465	4.584	5.034	3.944	1.607	7.250	EC.T.
LAT.+15 DEG	5.660	12.739	17.667	18.238	13.198	8.815	8.558	7.961	6.629	6.514	5.093	2.534	9.391	MEAN
	4.110	6.552	6.585	7.300	6.478	4.891	4.849	5.033	4.430	5.218	4.199	1.730	7.095	S.D.
90 DEG.	5.695	12.643	17.201	17.384	12.120	7.645	7.403	7.072	6.122	6.349	5.098	2.557	8.867	MOYEN
	4.132	6.497	6.400	6.930	5.995	4.157	4.150	4.486	4.127	5.142	4.213	1.749	6.765	EC.T.

RATIO OF 9 AM TO 3 PM RADIATION TO DAILY RADIATION: MEAN AND STANDARD DEVIATION
RAPPORT DU RAYONNEMENT DE 9 H A 15 H AU RAYONNEMENT QUOTIDIEN: MOYEN ET ECART TYPE

TILT ANGLE INCLINAISON	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
O DEG.	.997	.925	.772	.651	.578	.535	.556	.610	.720	.858	.986	1.000	.766	MEAN
	.008	.047	.046	.043	.052	.056	.067	.070	.057	.065	.021	0.000	.181	S.D.
LATITUDE	.999	.908	.765	.699	.644	.612	.637	.663	.731	.835	.988	1.000	.791	MOYEN
	.004	.066	.046	.046	.063	.077	.076	.083	.068	.077	.024	0.000	.156	EC.T.
LAT.+15 DEG	.999	.907	.764	.703	.649	.623	.650	.673	.732	.833	.988	1.000	.794	MEAN
	.004	.068	.046	.047	.065	.082	.080	.085	.069	.079	.025	0.000	.153	S.D.
90 DEG.	.999	.906	.764	.705	.649	.626	.656	.680	.733	.831	.988	1.000	.795	MOYEN
	.004	.068	.046	.047	.066	.084	.082	.086	.069	.080	.026	0.000	.152	EC.T.

FROBISHER BAY A (NWT) (2402300)

MEAN DAILY GLOBAL SOLAR RADIATION ON A SLOPED SURFACE (MJ / SQ METRE)
MOYENNE JOURNALIERE DU RAYONNEMENT SOLAIRE GLOBAL SUR UNE SURFACE INCLINE (MJ / METRE CARRE)

TILT INCL	AZM AZM	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOU	SEP SEP	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUEL	
0	0	0.871	3.881	10.568	18.184	20.130	17.848	16.086	11.907	6.925	3.551	1.127	0.341	9.252	MEAN
		0.5806	1.7992	3.3741	5.5715	7.0319	7.6471	7.2342	5.3539	3.1767	1.7694	0.6895	0.1635	8.4574	SD
30	0	0.407	1.440	3.674	10.129	15.501	14.768	12.754	7.979	3.849	1.982	0.589	0.189	6.082	MOYEN
		0.2595	0.7253	2.2165	3.6061	4.4471	5.3341	4.7906	2.8507	1.2266	0.8354	0.3060	0.0956	6.2936	EC
60	0	0.464	1.765	4.565	8.618	11.741	10.433	8.586	5.310	3.235	2.009	0.641	0.204	4.776	MEAN
		0.2829	0.7248	1.9278	2.9421	3.3477	3.0560	2.6181	1.7247	0.8923	0.7812	0.3240	0.0977	4.3820	SD
90	0	0.541	2.211	5.856	10.448	11.690	8.687	6.987	4.339	2.803	2.046	0.713	0.227	4.681	MOYEN
		0.3321	0.8763	1.8643	2.9496	3.9565	2.8180	2.2704	1.3705	0.7706	0.8563	0.3833	0.1055	4.2694	EC
30	270	0.989	4.357	11.358	18.594	19.894	17.454	15.863	11.910	7.000	3.775	1.281	0.364	9.349	MEAN
		0.6978	2.0423	3.5853	5.8603	7.2718	7.5770	7.3069	5.5253	3.5051	2.0307	0.8394	0.1811	8.4443	SD
60	270	1.169	4.999	12.585	19.573	19.373	15.963	14.475	11.137	6.703	3.953	1.452	0.428	9.257	MOYEN
		0.8479	2.4511	4.1318	6.6688	7.8794	7.3435	7.1852	5.5675	3.6891	2.3714	1.0183	0.2279	8.3587	EC
90	270	1.217	5.166	12.716	19.383	17.727	12.978	11.624	9.153	5.690	3.779	1.482	0.440	8.382	MEAN
		0.9012	2.5684	4.2369	6.8753	7.8766	6.1878	6.0578	4.8135	3.2846	2.4176	1.0785	0.2405	7.6800	SD
30	225	2.644	7.908	16.152	22.688	21.912	18.366	16.990	13.492	8.546	5.400	2.669	1.150	11.419	MOYEN
		1.8459	3.9293	5.3706	7.8258	8.6150	8.4116	8.1651	6.8297	4.7623	3.5029	1.9898	0.7233	9.4198	EC
60	225	3.854	10.458	19.302	24.741	21.563	16.668	15.518	13.028	8.808	6.387	3.688	1.711	12.056	MEAN
		2.7429	5.3846	6.7868	9.2384	9.2943	7.9773	7.8789	7.1342	5.4312	4.6511	2.9175	1.1292	9.6448	SD
90	225	4.177	10.824	19.121	23.432	18.743	12.732	11.737	10.408	7.581	6.243	3.911	1.875	10.810	MOYEN
		2.9743	5.5917	6.7702	8.9124	8.5297	6.0206	6.0122	5.8826	4.8667	4.7551	3.1420	1.2521	8.6443	EC
30	180	3.405	9.617	18.255	24.081	22.361	18.282	16.988	13.707	9.070	6.126	3.291	1.491	12.140	MEAN
		2.4186	4.9145	6.2938	8.5535	8.9682	8.5162	8.2591	7.1731	5.1603	4.2020	2.5429	0.9691	9.7203	SD
60	180	5.172	13.365	22.608	26.413	21.736	16.134	15.107	13.062	9.543	7.604	4.765	2.301	13.050	MOYEN
		3.7407	7.0742	8.2892	10.0808	9.4255	7.7454	7.6380	7.3739	5.9692	5.8428	3.8839	1.5564	10.1080	EC
90	180	5.698	14.125	22.472	24.333	18.169	11.669	10.783	9.967	8.200	7.592	5.153	2.557	11.626	MEAN
		4.1277	7.5001	8.2923	9.3164	8.1440	5.3522	5.2958	5.7232	5.2997	6.0804	4.2590	1.7457	9.0530	SD
30	135	2.656	7.852	16.027	22.635	21.712	17.733	16.391	12.952	8.300	5.275	2.613	1.149	11.200	MOYEN
		1.8646	3.9631	5.5502	7.9976	8.6845	8.2878	8.0021	6.7985	4.5446	3.4366	1.9553	0.7263	9.3250	EC
60	135	3.874	10.361	19.108	24.685	21.319	15.817	14.704	12.245	8.426	6.178	3.592	1.710	11.746	MEAN
		2.7741	5.4387	7.0885	9.4497	9.4067	7.8188	7.6888	7.0762	5.1230	4.5411	2.8605	1.1343	9.5738	SD
90	135	4.199	10.714	18.917	23.390	18.528	11.995	11.018	9.653	7.190	6.011	3.800	1.874	10.518	MOYEN
		3.0099	5.6511	7.1033	9.1020	8.6463	5.9095	5.8593	5.8311	4.5832	4.6376	3.0783	1.2579	8.6362	EC
30	90	1.000	4.299	11.219	18.536	19.608	16.514	14.985	11.172	6.700	3.642	1.225	0.363	9.050	MEAN
		0.7181	2.0759	3.7961	6.1191	7.4116	7.4215	7.0474	5.5078	3.2208	1.9527	0.8039	0.1844	8.2726	SD
60	90	1.186	4.919	12.388	19.488	18.991	14.734	13.327	10.149	6.294	3.770	1.373	0.427	8.859	MOYEN
		0.8760	2.4975	4.4317	6.9778	8.0701	7.1576	6.8520	5.5486	3.3420	2.2539	0.9680	0.2326	8.1786	EC
90	90	1.233	5.086	12.523	19.264	17.344	11.895	10.602	8.217	5.299	3.598	1.403	0.439	8.010	MEAN
		0.9294	2.6179	4.5284	7.1755	8.0158	6.0378	5.7435	4.7753	2.9949	2.2997	1.0281	0.2451	7.5610	SD

APPENDIX II

WORKSHEETS
FOR
SIZING
ESTIMATING SYSTEM LOSSES
AND
PERFORMANCE ANALYSIS

SIZING WORKSHEET #1: DEFINE SITE CONDITIONS

SYSTEM LOCATION:	LATITUDE:	LONGITUDE:
INSOLATION LOCATION #1: INSOLATION LOCATION #2:	LATITUDE: LATITUDE:	LONGITUDE: LONGITUDE:

MONTH	AMBIENT TEMPERATURE	INSOLATION AT TILT = LAT. - 15 deg.		INSOLATION AT TILT = LAT.		INSOLATION AT TILT = LAT. + 15 deg.	
	Degrees C	(MJ/m2. day)	(Peak Sun Hours)	(MJ/m2. day)	(Peak Sun Hours)	(MJ/m2. day)	(Peak Sun Hours)
Jan.							
Feb.							
Mar.							
Apr.							
May							
June							
July							
Aug.							
Sept.							
Oct.							
Nov.							
Dec.							

SIZING WORKSHEET #2: ESTIMATE LOAD

LOAD DESCRIPTION	AC & DC	LOAD CURRENT (amps)	LOAD VOLTAGE (volts)	AC LOAD (watts)	INVERTER EFFICIENCY (%)	DC LOAD (watts)	DUTY CYCLE (hrs/day)	DUTY CYCLE (days/wk)	DAILY LOAD (watt-hrs)	NOMINAL VOLTAGE (volts)		AMP-HOUR LOAD (ah/day)
TOTAL												

DESIGN LOAD (Total ampere-hour load)		AH/DAY
DESIGN PEAK CURRENT DRAW $\frac{\text{(DC load)}}{\text{(Nominal Voltage)}}$		AMPS

SIZING WORKSHEET #3: SIZE BATTERY BANK

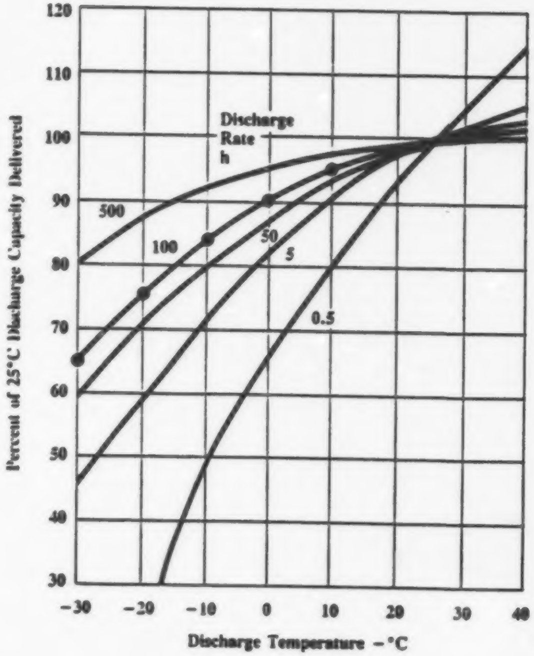
AMP-HOUR LOAD (amp-hrs/day)	X	DAYS OF AUTONOMY (days)	/	MAX. DEPTH OF DISCHARGE (fraction)	=	USABLE BATTERY CAPACITY (amp-hrs)
	X		/		=	

OPERATING TEMP. = (degrees C)

DISCHARGE RATE = 24 x DAYS OF AUTONOMY

= (HRS)

USABLE BATTERY CAPACITY (amp-hrs)	/	USABLE FRACTION OF CAPACITY AVAILABLE (from graph)	=	DESIGN BATTERY CAPACITY (amp-hrs)
	/		=	



SIZING WORKSHEET #4: SIZE ARRAY & PV COMPONENTS

OPERATING SEASON		Months
ARRAY TILT		Latitude + or - Degrees
LOWEST SOLAR RADIATION IN OPERATING SEASON (DESIGN PEAK SUN HOURS)		Peak Sun Hours

AMP-HOUR LOAD (amp-hrs/day)	/	LOWEST PEAK SUN HOURS (hrs/day)	/	MODULE LOSS FACTOR (fraction)	/	CHARGE REGULATOR EFFICIENCY (fraction)	/	BATTERY EFFICIENCY (fraction)	=	DESIGN ARRAY CURRENT (amps)
	/		/		/		/		=	

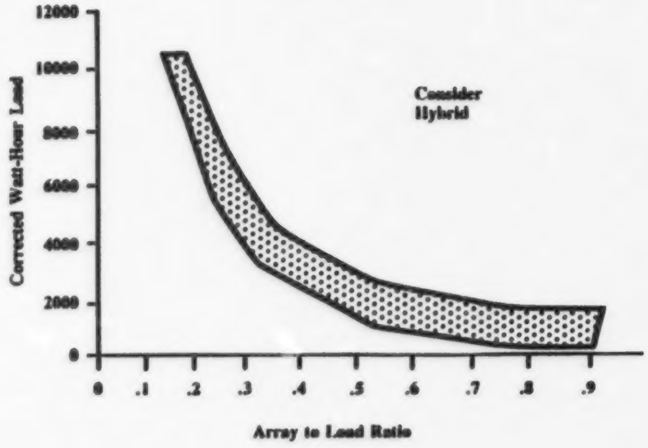
DESIGN ARRAY CURRENT (amps)	X	NOMINAL VOLTAGE (volts)	=	DESIGN ARRAY POWER (peak-watts)
	X		=	

DESIGN ARRAY CURRENT (amps)	=	DESIGN POWER CONDITIONER CURRENT (amps)
	=	

SIZING WORKSHEET #5: CONSIDER HYBRID

AMP-HOUR LOAD (amp-hrs/day)	X	NOMINAL VOLTAGE (volts)	=	WATT - HOUR LOAD (watt-hrs/day)
	X		=	

DESIGN ARRAY POWER (watt)	/	WATT - HOUR LOAD (watt-hrs/day)	=	ARRAY/LOAD RATIO
	/		=	



HYBRID DESIGN
(from Graph)

YES	NO

SIZING WORKSHEET #6: SIZE HYBRID

PHOTOVOLTAIC DESIGN PERIOD		Months
ARRAY TILT		Latitude + or - Degrees
LOWEST SOLAR RADIATION IN DESIGN PERIOD		Peak Sun Hours

AMP-HOUR LOAD (amp-hrs/day)	/	DESIGN PERIOD PEAK SUN HOURS (hrs/day)	/	MODULE LOSS FACTOR (fraction)	/	CHARGE REGULATOR EFFICIENCY (fraction)	/	BATTERY EFFICIENCY (fraction)	=	DESIGN ARRAY CURRENT (amps)
	/		/		/		/		=	

DESIGN ARRAY CURRENT (amps)	X	NOMINAL VOLTAGE (volts)	=	DESIGN ARRAY POWER (peak-watts)
	X		=	

DESIGN ARRAY CURRENT (amps)	X	LOWEST PEAK SUN HOURS	=	PV LOAD CONTRIBUTION (amp-hrs/day)
	X		=	

AMP-HOUR LOAD (amp-hrs/day)	X	DAYS OF AUTONOMY (days)	/	MAXIMUM DEPTH OF DISCHARGE (fraction)	/	USABLE FRACTION OF BATTERY CAPACITY AVAILBLE (from Worksheet #3)	=	DESIGN BATTERY CAPACITY (amp-hrs)
	X		/		/		=	

SIZING WORKSHEET #6: SIZE HYBRID (continued)

AMPERE-HOUR LOAD (amp_hr/day)	/	BATTERY EFFICIENCY (fraction)	/	RECTIFIER EFFICIENCY (fraction)	X	NOMINAL VOLTAGE (volts)	=	DESIGN GENERATOR LOAD (watt.hrs/day)
	/		/		X		=	

DESIGN GENERATOR LOAD (watt.hrs/day)	X	DAYS OF AUTONOMY	/	CHARGE TIME (hrs)	=	NOMINAL GENERATOR CAPACITY (watts)
	X		/		=	

SYSTEM LOSSES WORKSHEET

			DC	AC
A	LOAD (watts)			
	Wiring: Inverter to Load:			
	Type			
B	Length (ft)			
C	Resistance (ohms/1000 ft)			
D	Voltage (volts)			
E	Current (amps)	A/D		
F	Loss (watts)	$B * C * E^2/1000$		
	Inverter:			
G	Output (watts)	A + F		
H	Efficiecy (%)			
I	Input Power (watts)	G/H		
	Wiring: Battery to Inverter or Load:			
	Type			
J	Length (ft)			
K	Resistance (ohms/1000 ft)			
L	Voltage (volts)			
M	Current (amps)	I/L or A/L		
N	Loss (watts)	$J * K * M^2/1000$		
	Battery & Charge Controller			
O	Total power delivered (watts)	$(A+N)dc + (I+N)ac$		
P	Efficiency (%)			
Q	Input power (watts)	O/P		
	Wiring: Array to Battery:			
	Type			
R	Length (ft)			
S	Resistance (ohms/1000 ft)			
T	Voltage (volts)			
U	Current (amps)	Q/T		
V	Loss (watts)	$R * S * U^2/1000$		
	Array:			
W	Blocking Diode Voltage Drop (volts)			
X	Blocking Diode loss (watts)	W * U		
Y	Total Power delivered	Q + V + X		

PERFORMANCE WORKSHEET #1: MONTHLY ANALYSIS OF SYSTEM WITH STORAGE

ARRAY SIZE ________ WATTS ARRAY CURRENT ______ AMPS BATTERY SIZE ______ AH

	A	B	C	D [1]	E [2]	F [3]	G	H	I	J
MONTH	AVERAGE TEMP. (degrees C)	AVERAGE INSOLATION (Peak Hrs.)	ARRAY OUTPUT (AH/DAY)	AVERAGE LOAD (AH/DAY)	BATTERY DERATING FACTOR	BATTERY STORAGE START OF MONTH (AH)	NET POWER USED (AH)	BATTERY STORAGE END OF MONTH (AH)	RESERVE CAPACITY (DAYS)	DESIGN SATISFIED (YES/NO)
						E*(H/E Previous)	DAYS in month x (C - D)	Lowest of F or F - G + C	H/D	

Notes:
1. Load including system losses
2. Battery Derating Factor from Sizing Worksheet #3 at monthly temperature and charging rate
3. Battery Storage at start of first month equals nominal capacity times E.
Thereafter Battery Storage at start of month equals Battery Storage at end of previous month times ratio of current and previous derating factors.

PERFORMANCE WORKSHEET #2: MONTHLY ANALYSIS OF HYBRID SYSTEM

ARRAY SIZE ________ WATTS ARRAY CURRENT ________ AMPS BATTERY SIZE ________ AH ENGINE SIZE ________ WATTS

	A	B	C	D[1]	E[2]	F[3]	G[4]	H[5]	I	J	K
MONTH	AVERAGE TEMP. (degrees C)	AVERAGE INSOLATION (Peak Hrs.)	ARRAY OUTPUT (AH/DAY)	AVERAGE LOAD (AH/DAY)	BATTERY DERATING FACTOR	CHARGE PER CYCLE (AH)	PV CYCLE TIME (DAYS)	TOTAL CYCLE TIME (DAYS)	NUMBER OF CYCLES IN MONTH	DIESEL FRACTION	PV FRACTION
						Nom *0.6/E	F/(D-C)	G + 0.17	Days/H	I*F/(D*Days)	1 - J

Notes:
1. Load including system losses
2. Battery Derating Factor from Sizing Worksheet #3 at monthly temperature and charging rate
3. Charge per cycle assumes battery is charged from 20% to 80% i.e. nominal size times 0.6 divided by the Battery Derating Factor
4. If Array Output is greater than Load (C>D), assume that diesel is turned on every 10 days for 4 hours (0.17 days) - minimum 3 cycles per month
5. Assuming diesel recharges the battery in 4 hours

APPENDIX III

PRESENT WORTH FACTOR TABLES

Single Present Worth Factors

Net Discount Rate

Year		.01	.02	.03	.04	.05	.06	.07	.08	.09	.10	.11	.12
1		0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909	0.901	0.893
2		0.980	0.961	0.943	0.925	0.907	0.890	0.873	0.857	0.842	0.826	0.812	0.797
3		0.971	0.942	0.915	0.889	0.864	0.840	0.816	0.794	0.772	0.751	0.731	0.712
4		0.961	0.924	0.888	0.855	0.823	0.792	0.763	0.735	0.708	0.683	0.659	0.636
5		0.951	0.906	0.863	0.822	0.784	0.747	0.713	0.681	0.650	0.621	0.593	0.567
6		0.942	0.888	0.837	0.790	0.746	0.705	0.666	0.630	0.596	0.564	0.535	0.507
7		0.933	0.871	0.813	0.760	0.711	0.665	0.623	0.583	0.547	0.513	0.482	0.452
8		0.923	0.853	0.789	0.731	0.677	0.627	0.582	0.540	0.502	0.467	0.434	0.404
9		0.914	0.837	0.766	0.703	0.645	0.592	0.544	0.500	0.460	0.424	0.391	0.361
10		0.905	0.820	0.744	0.676	0.614	0.558	0.508	0.463	0.422	0.386	0.352	0.322
11		0.896	0.804	0.722	0.650	0.585	0.527	0.475	0.429	0.388	0.350	0.317	0.287
12		0.887	0.788	0.701	0.625	0.557	0.497	0.444	0.397	0.356	0.319	0.286	0.257
13		0.879	0.773	0.681	0.601	0.530	0.469	0.415	0.368	0.326	0.290	0.258	0.229
14		0.870	0.758	0.661	0.577	0.505	0.442	0.388	0.340	0.299	0.263	0.232	0.205
15		0.861	0.743	0.642	0.555	0.481	0.417	0.362	0.315	0.275	0.239	0.209	0.183
16		0.853	0.728	0.623	0.534	0.458	0.394	0.339	0.292	0.252	0.218	0.188	0.163
17		0.844	0.714	0.605	0.513	0.436	0.371	0.317	0.270	0.231	0.198	0.170	0.146
18		0.836	0.700	0.587	0.494	0.416	0.350	0.296	0.250	0.212	0.180	0.153	0.130
19		0.828	0.686	0.570	0.475	0.396	0.331	0.277	0.232	0.194	0.164	0.138	0.116
20		0.820	0.673	0.554	0.456	0.377	0.312	0.258	0.215	0.178	0.149	0.124	0.104
21		0.811	0.660	0.538	0.439	0.359	0.294	0.242	0.199	0.164	0.135	0.112	0.093
22		0.803	0.647	0.522	0.422	0.342	0.278	0.226	0.184	0.150	0.123	0.101	0.083
23		0.795	0.634	0.507	0.406	0.326	0.262	0.211	0.170	0.138	0.112	0.091	0.074
24		0.788	0.622	0.492	0.390	0.310	0.247	0.197	0.158	0.126	0.102	0.082	0.066
25		0.780	0.610	0.478	0.375	0.295	0.233	0.184	0.146	0.116	0.092	0.074	0.059
26		0.772	0.598	0.464	0.361	0.281	0.220	0.172	0.135	0.106	0.084	0.066	0.053
27		0.764	0.586	0.450	0.347	0.268	0.207	0.161	0.125	0.098	0.076	0.060	0.047
28		0.757	0.574	0.437	0.333	0.255	0.196	0.150	0.116	0.090	0.069	0.054	0.042
29		0.749	0.563	0.424	0.321	0.243	0.185	0.141	0.107	0.082	0.063	0.048	0.037
30		0.742	0.552	0.412	0.308	0.231	0.174	0.131	0.099	0.075	0.057	0.044	0.033
35		0.706	0.500	0.355	0.253	0.181	0.130	0.094	0.068	0.049	0.036	0.026	0.019
40		0.672	0.453	0.307	0.208	0.142	0.097	0.067	0.046	0.032	0.022	0.015	0.011
45		0.639	0.410	0.264	0.171	0.111	0.073	0.048	0.031	0.021	0.014	0.009	0.006
50		0.608	0.372	0.228	0.141	0.087	0.054	0.034	0.021	0.013	0.009	0.005	0.003
55		0.579	0.337	0.197	0.116	0.068	0.041	0.024	0.015	0.009	0.005	0.003	0.002
60		0.550	0.305	0.170	0.095	0.054	0.030	0.017	0.010	0.006	0.003	0.002	0.001
65		0.524	0.276	0.146	0.078	0.042	0.023	0.012	0.007	0.004	0.002	0.001	0.001
70		0.498	0.250	0.126	0.064	0.033	0.017	0.009	0.005	0.002	0.001	0.001	0.000
75		0.474	0.226	0.109	0.053	0.026	0.013	0.006	0.003	0.002	0.001	0.000	0.000

Uniform Present Worth Factors

Net Discount Rate

Year		.01	.02	.03	.04	.05	.06	.07	.08	.09	.10	.11	.12
1		0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909	0.901	0.893
2		1.970	1.942	1.913	1.886	1.859	1.833	1.808	1.783	1.759	1.736	1.713	1.690
3		2.941	2.884	2.829	2.775	2.723	2.673	2.624	2.577	2.531	2.487	2.444	2.402
4		3.902	3.808	3.717	3.630	3.546	3.465	3.387	3.312	3.240	3.170	3.102	3.037
5		4.853	4.713	4.580	4.452	4.329	4.212	4.100	3.993	3.890	3.791	3.696	3.605
6		5.795	5.601	5.417	5.242	5.076	4.917	4.767	4.623	4.486	4.355	4.231	4.111
7		6.728	6.472	6.230	6.002	5.786	5.582	5.389	5.206	5.033	4.868	4.712	4.564
8		7.652	7.325	7.020	6.733	6.463	6.210	5.971	5.747	5.535	5.335	5.146	4.968
9		8.566	8.162	7.786	7.435	7.108	6.802	6.515	6.247	5.995	5.759	5.537	5.328
10		9.471	8.983	8.530	8.111	7.722	7.360	7.024	6.710	6.418	6.145	5.889	5.650
11		10.368	9.787	9.253	8.760	8.306	7.887	7.499	7.139	6.805	6.495	6.207	5.938
12		11.255	10.575	9.954	9.385	8.863	8.384	7.943	7.536	7.161	6.814	6.492	6.194
13		12.134	11.348	10.635	9.986	9.394	8.853	8.358	7.904	7.487	7.103	6.750	6.424
14		13.004	12.106	11.296	10.563	9.899	9.295	8.745	8.244	7.786	7.367	6.982	6.628
15		13.865	12.849	11.938	11.118	10.380	9.712	9.108	8.559	8.061	7.606	7.191	6.811
16		14.718	13.578	12.561	11.652	10.838	10.106	9.447	8.851	8.313	7.824	7.379	6.974
17		15.562	14.292	13.166	12.166	11.274	10.477	9.763	9.122	8.544	8.022	7.549	7.120
18		16.398	14.992	13.754	12.659	11.690	10.828	10.059	9.372	8.756	8.201	7.702	7.250
19		17.226	15.678	14.324	13.134	12.085	11.158	10.336	9.604	8.950	8.365	7.839	7.366
20		18.046	16.351	14.877	13.590	12.462	11.470	10.594	9.818	9.129	8.514	7.963	7.469
21		18.857	17.011	15.415	14.029	12.821	11.764	10.836	10.017	9.292	8.649	8.075	7.562
22		19.660	17.658	15.937	14.451	13.163	12.042	11.061	10.201	9.442	8.772	8.176	7.645
23		20.456	18.292	16.444	14.857	13.489	12.303	11.272	10.371	9.580	8.883	8.266	7.718
24		21.243	18.914	16.936	15.247	13.799	12.550	11.469	10.529	9.707	8.985	8.348	7.784
25		22.023	19.523	17.413	15.622	14.094	12.783	11.654	10.675	9.823	9.077	8.422	7.843
26		22.795	20.121	17.877	15.983	14.375	13.003	11.826	10.810	9.929	9.161	8.488	7.896
27		23.560	20.707	18.327	16.330	14.643	13.211	11.987	10.935	10.027	9.237	8.548	7.943
28		24.316	21.281	18.764	16.663	14.898	13.406	12.137	11.051	10.116	9.307	8.602	7.984
29		25.066	21.844	19.188	16.984	15.141	13.591	12.278	11.158	10.198	9.370	8.650	8.022
30		25.808	22.396	19.600	17.292	15.372	13.765	12.409	11.258	10.274	9.427	8.694	8.055
35		29.409	24.999	21.487	18.665	16.374	14.498	12.948	11.655	10.567	9.644	8.855	8.176
40		32.835	27.355	23.115	19.793	17.159	15.046	13.332	11.925	10.757	9.779	8.951	8.244
45		36.095	29.490	24.519	20.720	17.774	15.456	13.606	12.108	10.881	9.863	9.008	8.283
50		39.196	31.424	25.730	21.482	18.256	15.762	13.801	12.233	10.962	9.915	9.042	8.304
55		42.147	33.175	26.774	22.109	18.633	15.991	13.940	12.319	11.014	9.947	9.062	8.317
60		44.955	34.761	27.676	22.623	18.929	16.161	14.039	12.377	11.048	9.967	9.074	8.324
65		47.627	36.197	28.453	23.047	19.161	16.289	14.110	12.416	11.070	9.980	9.081	8.328
70		50.169	37.499	29.123	23.395	19.343	16.385	14.160	12.443	11.084	9.987	9.085	8.330
75		52.587	38.677	29.702	23.680	19.485	16.456	14.196	12.461	11.094	9.992	9.087	8.332

Yearly Principal and Interest Per $1,000 Loan

Loan Rate		5-Year Loan	10-Year Loan	15-Year Loan	20-Year Loan	25-Year Loan
.08		243.32	145.59	114.68	100.37	92.62
.0825		244.76	147.18	116.42	102.25	94.61
.085		246.20	148.78	118.17	104.14	96.63
.0875		247.65	150.39	119.93	106.05	98.66
.09		249.10	152.01	121.71	107.97	100.70
.0925		250.56	153.64	123.50	109.90	102.77
.095		252.02	155.28	125.31	111.86	104.84
.0975		253.49	156.92	127.12	113.82	106.94
.1		254.96	158.58	128.95	115.80	109.04
.1025		256.44	160.25	130.79	117.80	111.17
.105		257.93	161.92	132.65	119.81	113.30
.1075		259.42	163.61	134.51	121.83	115.45
.11		260.91	165.30	136.39	123.86	117.61
.1125		262.41	167.00	138.28	125.91	119.79
.115		263.91	168.71	140.18	127.97	121.98
.1175		265.42	170.44	142.10	130.04	124.18
.12		266.93	172.17	144.02	132.13	126.39
.1225		268.45	173.90	145.96	134.23	128.61
.125		269.98	175.65	147.90	136.34	130.84
.1275		271.50	177.41	149.86	138.46	133.09
.13		273.04	179.17	151.83	140.59	135.34
.1325		274.58	180.95	153.81	142.73	137.60
.135		276.12	182.73	155.80	144.88	139.88
.1375		277.67	184.52	157.80	147.05	142.16
.14		279.22	186.32	159.81	149.22	144.45
.1425		280.78	188.13	161.83	151.41	146.75
.145		282.34	189.94	163.86	153.60	149.06
.1475		283.91	191.77	165.90	155.80	151.38
.15		285.48	193.60	167.95	158.01	153.70
.1525		287.06	195.44	170.01	160.24	156.03
.155		288.64	197.29	172.08	162.47	158.37
.1575		290.23	199.15	174.16	164.70	160.71
.16		291.82	201.02	176.24	166.95	163.07
.1625		293.41	202.89	178.34	169.21	165.42
.165		295.01	204.77	180.45	171.47	167.79
.1675		296.62	206.66	182.56	173.74	170.16
.17		298.23	208.56	184.68	176.02	172.54
.1725		299.85	210.46	186.81	178.30	174.92
.175		301.47	212.37	188.95	180.59	177.30
.1775		303.09	214.29	191.10	182.89	179.70
.18		304.72	216.22	193.25	185.20	182.09

MULTIPLY THE COST PER $1000 BY THE SIZE OF THE LOAN (IN THOUSANDS OF DOLLARS)

APPENDIX IV

OTHER SOURCES OF INFORMATION

BUYERS' GUIDES:

1. *Photovoltaic Systems: A Buyers Guide.* Energy, Mines and Resources Canada, Ottawa (to be published mid 1989)

OTHER DESIGN MANUALS AND AIDS:

1. *Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices.* SANDIA National Laboratories, Albuquerque, New Mexico, USA. SAND87-7023 April 1988

2. *Photovoltaics: A Manual for Design and Installation of Stand-Alone Photovoltaic Systems.* Appropriate Technology Associates, Carbondale, Colorado, USA.

3. Computerized sizing programs are available from the *WATSUN User Service*, University of Waterloo, Ontario

SOLAR RADIATION DATA:

1. *Solar Radiation Data Analyses for Canada 1967-1976.* Atmospheric Environment Service, Environment Canada. Ministry of Supply and Services Canada 1985
   Volume 1: Atlantic Provinces
   Volume 2: Quebec
   Volume 3: Ontario
   Volume 4: Prairie Provinces
   Volume 5: British Columbia
   Volume 6: Yukon and Northwest Territories

CODES AND STANDARDS:

1. Canadian Standards Association (CSA), Standard CAN/CSA-M380-M87, "Photovoltaic Modules"

2. *Supplement to the National Building Code of Canada.* 1980, 1985, National Research Council

3. *Canadian Electrical Code.* Canadian Standards Association (CSA)

4. United States National Electrical Code (NEC) Section 690: *Photovoltaic System Inspection.*

CLIMATE DATA

1. Canadian Climate Normals 1951 - 1980

   Atmospheric Environment Service, Environment Canada

   Volume 1: Radiation

   Volume 2: Temperature

   Volume 3: Precipitation

   Volume 4: Degree Days

   Volume 5: Wind

   Volume 6: Frost

2. Typical Meterological Years (TMY) for several locations in Canada are available from the WATSUN User Services, University of Waterloo, Ontario